SEMIANNUAL REPORT OF ACTIVITIES

SUPPORTED BY AND RELATED TO

NASA GRANT NsG-269-62

MULTIDISCIPLINARY RESEARCH IN SPACE-RELATED SCIENCE AND TECHNOLOGY

30 September 1965

This research program is carried out in
The Earth and Planetary Sciences Laboratory
Francis S. Johnson, Director

This Laboratory is one of several within
The Southwest Center for Advanced Studies
Lloyd V. Berkner, Director

The Southwest Center for Advanced Studies is the research arm of
The Graduate Research Center of the Southwest
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PREFACE

This report includes a summary of all activities supported by NASA Grant NsG-269-62, and of all other activities closely enough related to these to be judged of probable interest to NASA. The activities summarized herein that are not supported by the NASA grant are supported in a variety of ways. The sources of government support include National Science Foundation, Air Force Office of Scientific Research, Office of Naval Research, Air Force Cambridge Research Laboratories, and NASA (contracts). In addition, a sizeable contribution is provided by the local community in unsponsored research funds, funds for unrecovered overhead, and the very substantial facility in which the program can be carried out; the community support far exceeds the total funds received from the government on grants and contracts supporting the research program.

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FUNDAMENTAL RESEARCH IN EARTH AND PLANETARY SCIENCES

A BROAD PROGRAM SUPPORTED BY OR RELATED TO

NASA GRANT NsG-269-62

SOUTHWEST CENTER FOR ADVANCED STUDIES

30 SEPTEMBER 1965

A. General Objectives

The overall objective of the research program of the Earth and Planetary Sciences Laboratory at the Southwest Center for Advanced Studies is to develop as fully as possible an understanding of the earth including its atmosphere and the processes by which it has reached its present state. This same objective applies with regard to the planets, the moon, and the interplanetary or solar environment in which they are located. Also included is an interest in cosmology. The characterizing feature of the entire research program is its breadth, which enables each research area to draw strength from the other research areas. The programs supported at SCAS by NASA Grant NsG-269-62, and closely allied programs supported by NASA and other agencies, thus constitute a broad interdisciplinary approach to space research.

The basic NASA grant is carefully apportioned to specific research projects in order to assure that the supported activities are highly responsive to NASA scientific program objectives. In addition to the basic grant, supplemental funding from the program offices was provided through the grant instrument, starting in April, 1964; this provided additional support for specified portions of the program. Further, many contracts with NASA provide for specific experiments to be performed in space vehicles. A number of grants and contracts with other government agencies involve activities that relate to NASA interests. As a result, several programs of the Laboratory not supported by NASA provide very direct advantages to NASA through the development of theories, sophisticated techniques, and equipment that can be applied advantageously to future objectives of the space program. A summary of contracts and grants from all government agencies is presented in Section E.

The research activities at SCAS mainly support the following four program areas of the NASA Space Sciences program: Planetary Atmospheres, Ionospheric and Radio Physics, Particles and Fields, and Planetology. The recent rapid development at the Center of a research program in molecular biology may well lead to interdisciplinary research in exobiology.

B. Research Program

The program descriptions described under this section describe the total research effort of the Center relevant to NASA's interests without respect to sources of funding, whether by the Center, NASA, or other sources. However, sources of funding other than the NASA grant are usually mentioned. The interlocking features of the research program make its orderly description difficult. The division into the different areas described below is rather arbitrary, but it serves to illustrate the apportionment of effort.

1. History of the Earth's Atmosphere

The composition of the earth's atmosphere at each interval throughout the various geological eras has a very direct bearing on the geological formation of the earth's crust and the origin of life. In preliminary work last year, Professors L. V. Berkner and L. C. Marshall were able to show how the oxygen concentration in the atmosphere could be traced over geological time. During the present year this work has been extended and refined.

The time schedule for the rise of oxygen in the atmosphere is inferred as follows:

Era	Date	Oxygen Concentration
Early eras	prior to 1.2 billion yrs.	0.1 percent present
Opening of Cambrian	600 million years	1 percent present
Late Silurian	420 million years	10 percent present
Carboniferous	300 million years	present (or above)

In the present studies, Berkner and Marshall are working on the ozone concentration corresponding to these concentrations of oxygen in the various eras. This has led to a study of the probable history of the rise of nitrogen concentration over geological time, since nitrogen is the most probable constituent involved in ozone formation by three-body collisions. The ozone concentrations in turn determine the extent of protection of surface and water swelling organisms, since ozone is the only probable constituent capable of absorbing lethal ultraviolet light from the sun in the range 2400 to 3000 angstroms. Likewise, production of ozone near the earth's surface in the primitive atmosphere leads to the main loss of atmospheric oxygen through rapid oxidation of surface materials. Moreover, because ozone absorbs heat, the height of the ozone region, and its concentration at any era, will determine the lapse rate and the general convective state of the atmosphere. The work on nitrogen and certain other atmospheric constituents is continuing in order to extend our understanding of the primitive atmosphere. This work also has important implications relative to the Martian atmosphere and its evolution.

The lethal level of ultraviolet radiation with respect to primitive organisms is very uncertain. Collaborative work with the Division of Genetics has been initiated in the endeavor to define in terms of precise energy levels the limiting rates of mutation under which typical primitive populations can survive under ultraviolet of various lengths of exposure. The present data are uncertain by more than a factor of ten, and these data relate intimately to the application of paleontological evidence to more precise estimation of oxygen concentration.

Most recently, studies of the shielding effect of oxygen on the dissociation of H_2O (Urey effect) have been extended. The roles of O_2, H_2O, and CO_2 have been calculated over the dissociative band in further refining the limits of oxygen in a primitive atmosphere. Briefly, it has become established that water vapor plays a major role in absorption of the atmosphere as long as the oxygen pressure is less than 10^{-3} present oxygen concentration. In the neighborhood of this concentration, the shielding effect of oxygen enters, and above this concentration, it plays a major role, completely dominating the scene at concentrations of the order of 2×10^{-3} to 5×10^{-3} of present level. Carbon dioxide on the other hand has a modifying effect which is minor in nature.

2. Atmospheric Structure

(a) Transport Processes

The structure of the upper atmosphere can be described in terms of the composition and temperature profiles through the atmosphere. These in turn are strongly influenced in the upper thermosphere by molecular transport processes and in the lower thermosphere by eddy transport processes. The transition region in which both are important is of particular interest, since the physical processes occurring there exert an important influence on higher levels of the atmosphere.

The relative amounts of atomic and molecular oxygen in the middle and upper thermosphere are directly related to the eddy mixing rate at the turbopause and the rate of dissociation of molecular oxygen by solar ultra-violet light. Since the photodissociation rate is reasonably well known, measurements of the O/O_2 ratio in the thermosphere give sufficient information to determine the average rate of eddy mixing at the turbopause. Colegrove, Hanson, and Johnson (1965) have calculated the transport of atomic and molecular oxygen and have shown the relationship that exists between mixing

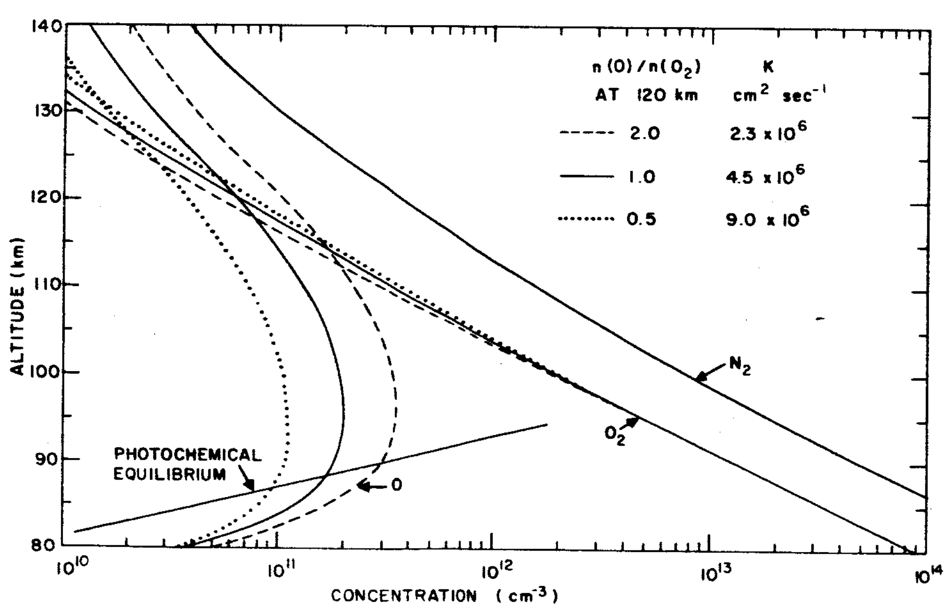

Figure 1 - Altitude dependence of the major components of the atmosphere for three values of the atomic to molecular oxygen ratio at 120 km. The eddy diffusion coefficient, K, is assumed constant in this region.

at the turbopause and the atmospheric atomic and molecular oxygen concentrations. Figure 1 gives the concentrations of the major constituents for three different values of the eddy diffusion coefficient.

Similar calculations have now been made which give the concentrations of minor constituents in the earth's atmosphere that are consistent with reasonable mixing rates and oxygen concentrations. One model consistent with recently measured values of atomic and molecular oxygen is shown in Figure 2. The significance of these results is that, for a fixed mixing

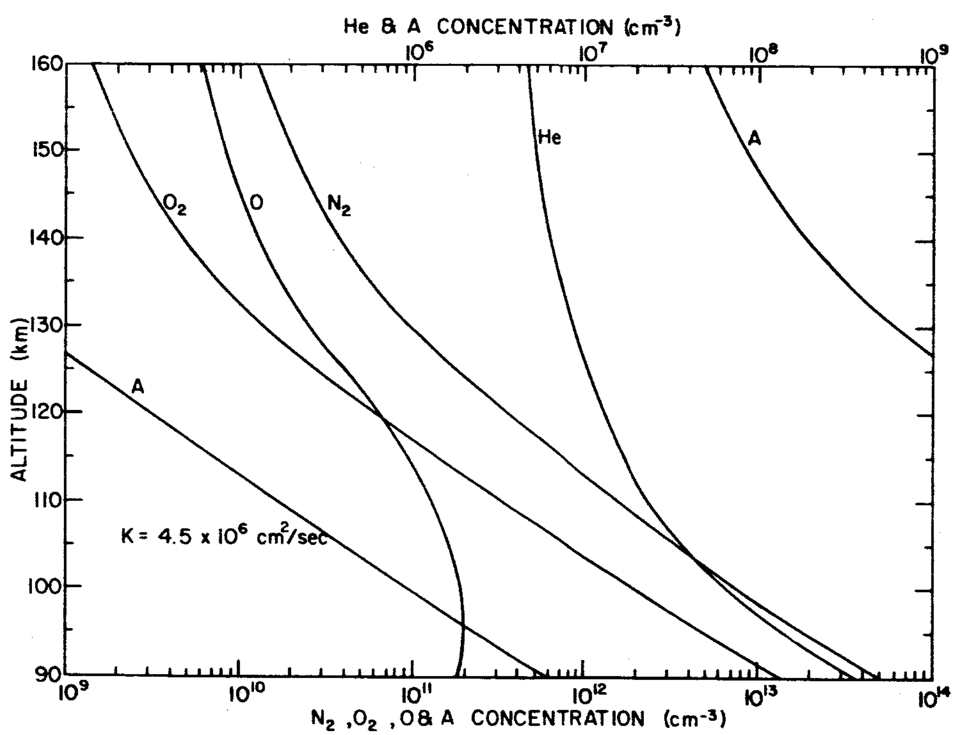

Figure 2 - Atmospheric composition for an average eddy diffusion coefficient of 4.5×10^6 $cm^2 sec^{-1}$.

rate, diffusion separation begins at different levels for different atmospheric constituents. It is proposed that the turbopause for each constituent is best described as that level at which the molecular diffusion coefficient equals the prevailing average eddy diffusion coefficient.

Further studies are being conducted into the effect of large scale motions upon the neutral composition of the upper atmosphere.

(b) Atmospheric Oscillations

The linearized theory of oscillations in the earth's atmosphere has been extensively developed at the Southwest Center for Advanced Studies by Drs. J. E. Midgley and H. B. Liemohn. The dispersion equation and polarization relations for the homogeneous isothermal case were first worked out by Hines (1960), but their properties were never fully investigated. A detailed analysis of these relations has clarified the relationship of the acoustic and gravity waves discussed by Hines to other types of waves excluded from his discussion.

It has been found that all types of waves (even the apparently unrelated Brunt-Vaisala oscillations) are included in Hines relations if they are interpreted more generally. The appropriate way to plot the dispersion equation for these atmospheric waves is to use the period and horizontal phase velocity as variables, rather than the conventional wave number components k_x and k_z. When this is done, quite marked symmetries are revealed between acoustic waves at short periods and high phase velocities and gravity waves at long periods and low phase velocities. The intervening region corresponds to horizontally propagating waves which decay or grow with altitude and are referred to as "evanescent." The physical mechanism behind the varying properties of these waves has been explained for the first time in terms of three fundamental vertical forces. Also the conditions for coupling one type of wave to another across a discontinuity are elucidated. While it is possible in principle to couple an acoustic to a gravity wave, the parameters do not vary nearly enough in the earth's atmosphere to do so.

The major part of the work on gravity waves at SCAS has been directed toward solving the full linearized equations for the real atmosphere including molecular and turbulent dissipation. The viscous and thermal dissipation terms each increase the order of the equations by two, and thus introduce four new solutions. Low in the atmosphere, where the effect is small, these new solutions are severely damped in the direction of their propagation; but since two propagate up and two propagate down, no matter which way the numerical integration is performed there will be two rapidly growing solutions which are incompatible with the boundary conditions. This fact has prevented the inclusion of viscosity in any problems in the past except where it was either a large effect or a small effect and could be included by an approximation which did not raise the order of the equations. Since this problem satisfied neither limiting condition, it was necessary to develop an entirely new method of solution. Two methods were developed. The first was an exact method involving successive integration to remove the solutions in order of their dominance. The method is being published (Midgley, 1965) as a tool for others faced with similar problems; but, because of a characteristic of the atmospheric, it was too difficult to apply to the gravity wave problem. The second method is an approximate one, but it is capable of any required degree of precision with sufficient labor. The atmosphere is divided into thin layers in which the parameters are constant, and the analytic solutions for the six waves in each layer are then matched across the boundaries.

The trick is to use the matching conditions in such a way that the rapidly growing solutions are always determined at the point where they are largest, whether that be the top or the bottom of the layer. Every matching then will affect amplitudes in the layer both above and below it so that successive iterations are required. It converges well, however, and the results are insensitive to the layer thickness if it is less than 2 km. Using this method, calculations have been made for all ω and k_x of interest, and the wave properties such as height of maximum amplitude determined.

(c) Composition Measurements

Two mass spectrometers have been built by Dr. W. B. Hanson and T. W. Flowerday under NASA contract NASr-177. The first of these is a Paul massenfilter with an ionization section so that it can be used for the analysis of neutral gas. The second is a first-order focussing ninety-degree deflection magnetic spectrometer. A successful flight in Nike-Apache rocket 14.62 UA took place on March 18, 1965. The data have been reduced, and a final report has been submitted to NASA. Although only a limited amount of useful aeronomic information was gained from this flight, the shot must be considered a success. The following items are considered noteworthy:

(1) Both the neutral and the ion mass spectrometers functioned well.

(2) The very low power ion source (oxide cathode) which was activated in flight worked well and shows promise for satellite application.

(3) The first successful mating of a flight mass-spectrometer

with an ion (electron) multiplier detector was achieved.

(4) It was shown that the ion current collected by the ion spectrometer is a sensitive function of the draw-in electric field.

Some work has been done on an ion source for use with a neutral mass spectrometer that utilizes an orientated satellite's own motion to discriminate between ambient atmospheric gases and contaminate gases associated with the presence of the vehicle. Testing such a device to see how well it operates is difficult in the laboratory, because a source of neutral gas moving at satellite velocity is not readily available. For this reason, a preliminary effort is being made to produce such a neutral beam by charge exchange of a fast beam of ions in their parent gas.

3. Ionospheric Structure

(a) Equatorial F-Region

The effects of ionization transport on the electron distribution in the equatorial F-region have been investigated at SCAS by Drs. W. B. Hanson and R. J. Moffett. In particular, a quantitative treatment of the Appleton anomaly has been sought. Since the preliminary report of the work (Moffett and Hanson, 1965), the solutions of the electron continuity equation have been improved and extended. The equation includes photo-ionization, recombination, ambipolar diffusion and electrodynamic drift perpendicular to the magnetic field lines. In addition, the ionization motion caused by a north-south wind in the neutral atmosphere has been inserted.

Calculations have been performed for various values of the upward drift in the atmosphere under noon sunspot-maximum conditions, and under noon sunspot-minimum conditions. Figure 3 shows contours of

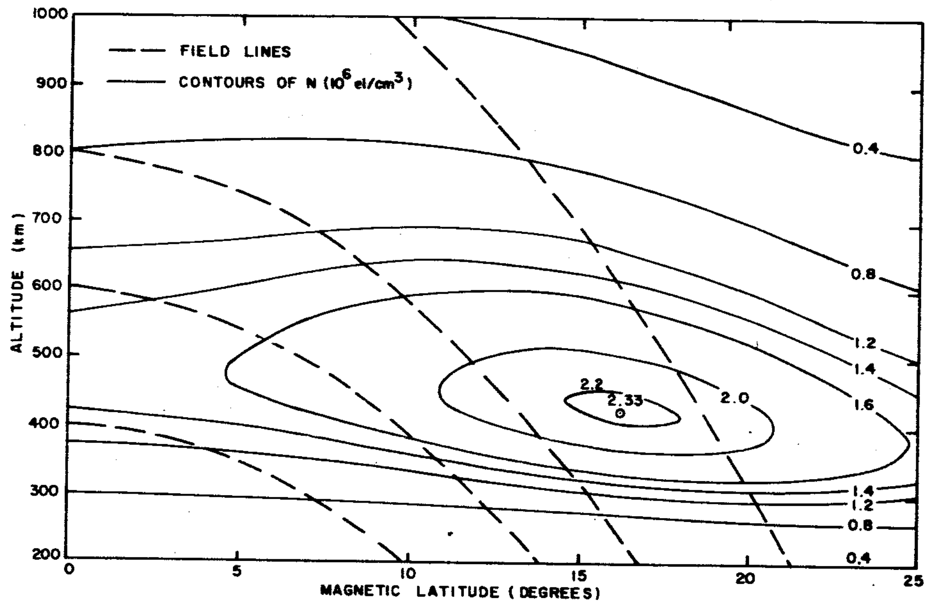

Figure 3 - Sunspot maximum conditions: $T_i = T_e/2 = 1500^oK$. At 400 km: $P = 1.8 \times 10^2$ $cm^{-3}sec^{-1}$, $\beta = 8.0 \times 10^{-5}$ sec^{-1}, $D_a = 1.3 \times 10^{11}$ cm^2sec^{-1}, $n(0) = 2 \times 10^8$ cm^{-3}, $v_o = 10$ m/sec independent of altitude.

electron concentration at sunspot maximum for an upward drift velocity of 10 m/sec. It is apparent that drifts of this order, which are consistent with those predicted by "dynamo" theory, can be responsible for the Appleton anomaly. The electron fluxes present in this case are plotted in Figure 4, and they provide a striking illustration of the "fountain effect" originally envisaged by Martyn (1955) when he suggested the electrodynamic drift as an explanation of the anomaly.

The presence of a north-south wind requires integration of the continuity equation to be carried out over both hemispheres. First results show that the velocity of such a wind has to be considerably greater in magnitude than an upward drift to cause similar effects.

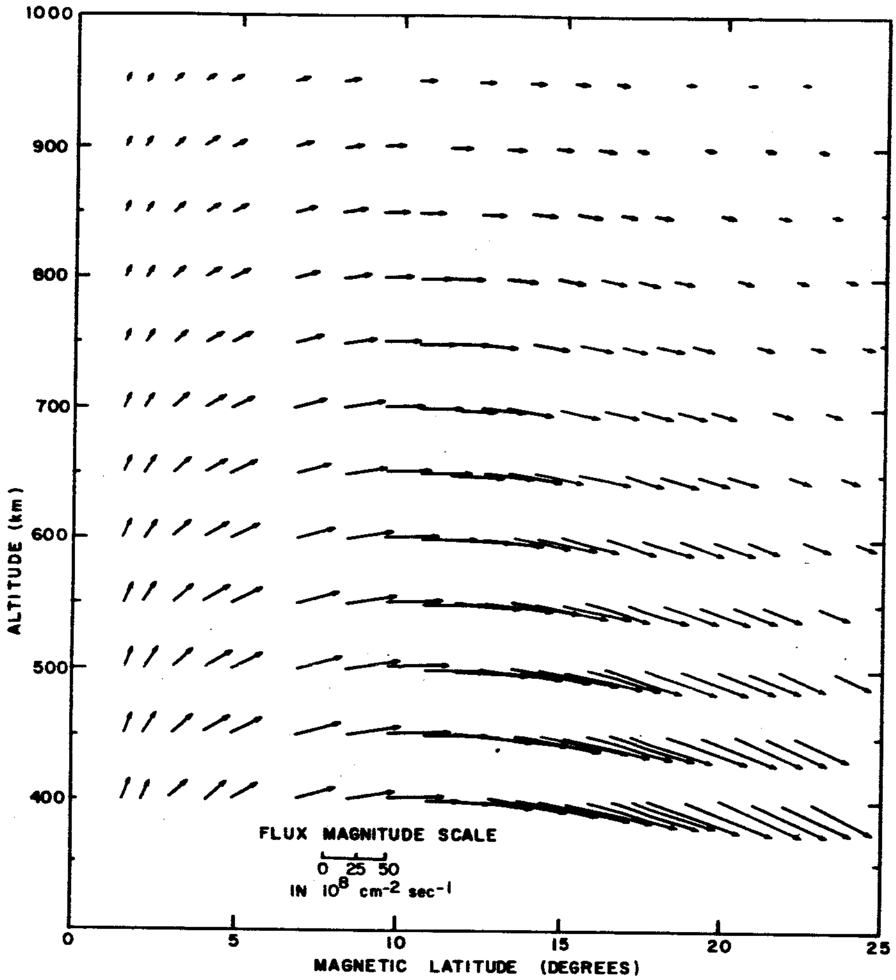

Fig. 4 - Sunspot maximum conditions: $T_i = T_e/2 = 1500^oK$. At 400 km: $P = 1.8 \times 10^2\ cm^{-3}sec^{-1}$, $\beta = 8.0 \times 10^{-5}\ sec^{-1}$, $D_a = 1.3 \times 10^{11}\ cm^2sec^{-1}$, $n(0) = 2.0 \times 10^8\ cm^{-3}$. v_o = 10 m/sec independent of altitude.

(b) D-Region

The lower ionosphere is characterized by the usual presence of a very small concentration of electrons, and, it is believed, negative ion concentrations which may exceed that of the electrons below 65 km. As the electron collision frequency in this region is quite large, any perturbation of the electron concentration produces serious effects upon telecommunications which use radio waves propagating through the lower ionosphere. Thus it is important to understand the structure and processes of this part of the ionosphere.

At present it is generally thought that the dominant negative ion in the lower ionosphere should be O_2^-, formed in the three-body attachment process

$$O_2 + O_2 + e \rightarrow O_2^- + O_2$$

However, there is some recent evidence (Hodges, 1965) that a two-body process is involved between 45 and 65 km. This is supported by the rate coefficient for two-body attachment deduced by Manning (1964) from meteor trail observations.

The state of experimental knowledge of the ionic composition of the lower ionosphere consists of the results of one quadrupole mass spectrometer experiment (Narcisi and Bailey, 1965) in which the concentrations of positive ions above 64 km were measured. Those results indicated the presence of some unsuspected ion species, and perhaps more disturbing, that the concentration of positive ions of mass number greater than 45 accounted for about half the total positive ion content between 65 to 75 km.

The confusion that exists regarding the structure and processes of the lower ionosphere is coupled with a lack of proven experimental techniques for this region. The quadrupole mass spectrometer is probably capable of detecting concentrations of ions not less than 10^3 cm^{-3} at 60 km. In addition, this device is not likely to be adaptable to the measurement of negative ion concentrations because it employs an electric field intensity of the order of 1000 volts per centimeter, whereas the electron affinity of negative ions is probably only a few eV.

Current effort by Dr. R. R. Hodges at SCAS includes the determination of the feasibility of an ion gyroresonance mass spectrometer. Present indications are that such a device should be capable of detecting, and discriminating, species of ions with mass numbers up to 50, in concentrations as small as 10^2 ions per cubic centimeter, at 50 km. Such a device would use an electric field intensity of less than one volt per centimeter, and thus would not be expected to significantly affect the detachment of electrons from negative ions. It appears that a static magnetic field of a few thousand Gauss would be necessary, but the small volume of the detector makes this requirement feasible.

In addition the problem of direct measurement of the electron attachment rate between 45 and 65 km has been considered; and an alternative approach to that used by Hodges (1965) has been developed. Also a probe to detect the mean values of the relative concentration-to-mass ratios of positive and negative ions in the lower ionosphere has been devised. A proposal is being prepared for a research program in which these devices will be employed in rocket-borne experiments to study the structure of the lower ionosphere.

(c) Time Dependent Structure of the Heliosphere

Helium ions are produced in the upper atmosphere by the action of solar radiation at a rate of about 10^{-7} ions/sec. They are destroyed by the processes

$$He^+ + N_2 \rightarrow He + N^+ + N \tag{1}$$

and

$$He^+ + O_2 \rightarrow He + O^+ + O \quad . \tag{2}$$

Although there is still some controversy concerning the relative importance of these reactions, it is assumed that process (2) is the more important destruction mechanism with a rate constant of 1.3×10^{-9} cm^3 sec^{-1}. With these values for the destruction and loss rates, it can be shown that about as many He^+ ions are created as destroyed in the midday ionosphere between the altitudes of 350 and 600 km. This suggests that steady state theories might not be applicable to the situation.

The most detailed measurement of the distribution of He^+ ions has been made by Taylor, Brace, Brinton, and Smith (1963); this indicates that the peak ion concentration lies at about 550 km. It is difficult to understand this on the basis of diffusive equilibrium theory (Bates and Patterson, 1964).

To obtain a better understanding of the heliosphere, an attempt is being made at SCAS by Drs. W. B. Hanson and T. N. L. Patterson to solve the appropriate time dependent equations describing the distribution of He^+ ions. These consist of the time-dependent continuity equation together with the equation of diffusion. Models have been constructed describing the time-dependent structure of the neutral atmosphere and the O^+ ion distribution. The presence of H^+ ions has been neglected, which is a satisfactory approximation except at low temperatures. An implicit method has been adopted for the solution of the partial differential equation.

The principal problem arises through the difficulty in unambiguously specifying the boundary conditions and hence avoiding the introduction of spurious solutions. At high altitudes, where diffusive equilibrium must prevail, dn/dz and $n/2H$ must closely balance to insure that the flux is small (n is the He^+ ion concentration, z is the altitude, and H is the scale height of neutral helium). However, since dn/dz must be evaluated numerically, with a resulting error, it is difficult to prevent the flux becoming large and hence disturbing the lower regions. In practice this difficulty is removed by artificially causing the diffusion coefficient to decrease exponentially with altitude at high altitudes.

A more serious problem arises at low altitudes. It is here that the most rapid changes in the ion concentration occur due to the much greater loss coefficient. These rapid changes are difficult to describe numerically, and a detailed study of the solutions indicates that very small time increments must be used (of the order of a few seconds) around the time of sunset, if a diverging solution is to be avoided. At present the computer program is being developed to allow automatic adjustment of the time increment and hence make it possible to follow the rapid changes in the He^+ concentration in the low altitude region.

(d) Multiple Ionospheric Probe

A rocket payload consisting of five different types of probes for local measurements of electron concentration and electron temperature has been constructed and flown under Contract No. NSR 44-004-017. The purpose of the program was to compare the operation of the different types of probes in order to permit detailed and quantitative comparison and evaluation of their performance. Briefly, these probes were as follows:

(1) The "Resonance Relaxation Probe," designed and instrumented by CRPL, was designed to detect plasma resonances of the types seen on topside sounder records.

(2) The measurement of the impedance of a sphere as a function

of frequency, carried out by Dr. J. A. Fejer and K. Tipple.

(3) The measurement of a resonant increase in the dc current collected by a probe under the influence of rf excitation, similar to a technique used by Japanese workers; this was done in conjunction with (2) above.

(4) The high frequency capacitance probe, which is a special case of the impedance probe, designed by W. J. Heikkila and N. Eaker.

(5) The measurement of dc current with three different collectors, also instrumented by W. J. Heikkila and N. Eaker.

Two launchings were carried out on September 1 and September 3, 1965, at Wallops Island, Virginia. Good data were obtained on the first flight during the daytime, but not on the second (nighttime) flight, due to clamshell and antenna failures. During the successful daytime flight, all probes gave good data, the resonance relaxation probe, showing strong resonances as soon as antenna deployment began at 130 kilometers, and the other probes showing responses above 85 km. Preliminary evaluation of the data suggests that all the objectives of the daytime flight will be accomplished. The third and final payload that was constructed during the program will be launched near the end of the year during nighttime conditions, after the antenna and clamshell failures have been fully analyzed and the deficiencies corrected.

The resonance relaxation experiment showed strong resonances almost immediately after antenna deployment began, proving that such resonances could indeed be excited with fairly short antennas. Four major resonances were observed; these being the electron gyro frequency, the plasma frequency, the upper hybrid frequency, and the second harmonic of the gyro frequency.

The resonances were also observed in a second mode of operation with this probe, in which only the receiver was operated while the variable frequency probe was on with its swept rf signal on the sphere. A strong signal was coupled to the receiver, and this was strongly affected by resonances throughout the ionosphere down to a height of 100 kilometers on the descending portion of the trajectory. The four resonances mentioned above were generally consistent throughout the flight, within an error of the order of 2 or 3 percent. Two other resonances were evident, one slightly above the electron gyro frequency and another near the plasma frequency; these two extra resonances have not yet been identified.

The variable frequency impedance probe showed a well-developed resonance behavior at frequencies some 20% below the plasma frequency during the upper portions of the flight when the plasma frequency was well above the gyro frequency. At lower heights, where the plasma frequency was below the gyro frequency, the resonance remained above the gyro frequency. A resonant increase in dc current to the probe was observed at the same time. The data thus convincingly support the theory that the resonances are indeed well below the plasma frequency when the magnetic field is weak. It appears, however, that antenna impedance in a magnetoionic medium is strongly influenced by the magnetic field, and a theory not taking this into account is not adequate. A second weaker resonance in the sphere impedance was also noticed through much of the flight.

The high frequency capacitance probe operated well throughout the flight with good sensitivity. The correction required for ion sheath effects in order to bring the high frequency capacitance measurements into agreement with the resonance relaxation measurements of electron concentration is of the order of a factor of 2. This correction is a strong function of the probe potential. The combined measurements of capacitance and ion current as a function of sphere potential will permit a very thorough check of the theory of operation of spherical electrostatic probes, such as the theory of Bernstein and Rabinowitz (1959). The expected advantages of this type of probe were fully borne out by the data; namely, simplicity of operation and high time and space resolution.

In passing, it might be noted that this Apache payload was probably the most complex ever launched, incorporating five different types of experiments, plus a multitude of auxiliary instrumentation, with a total of nearly 1,000 transistors. Not a single electronics failure has been indicated by the flight data in either flight.

The results of this experimental program would appear to permit a very intelligent choice of probe to be made for any particular purpose.

(e) Ionospheric Duct Detector

Work has been done on an instrument to investigate irregularities of electron concentrations in the ionosphere (Ionospheric Duct Detector). This instrument consists of a planar ion trap which is operated in two modes. In one mode it operates as a conventional ion trap measuring ion temperature, composition, and concentration. In the other mode, it measures irregularities in the relative ion concentration as small as $dn_i/n_i = 10^{-3}$. The limitation on scale size is determined by the telemetry bandwidth available to the instrument. One of these instruments has been constructed and successfully tested in the laboratory. This instrument has been proposed by Dr. W. B. Hanson and T. W. Flowerday for flight in an oriented satellite such as POGO.

4. Plasmas

(a) Excitation of the Hybrid Resonances by an Antenna in the Ionosphere

This is an extension of previous work (Deering and Fejer, 1965) in which a combination of Vlasov's equation with the equations of electrostatics (the "electrostatic" approximation) was used to calculate the excitation of resonant plasma oscillations by an infinitesimally small pulsed dipole source.

One of the approaches pursued at present by Dr. J. A. Fejer uses the full Maxwell equations instead of those of electrostatics. Similar work has been carried out by others (Nuttall, 1965; Shkarofsky and Johnston, 1965) who, however, failed to state the limits of validity of their approximations. The present work is aimed at filling in this gap.

Another simpler approach makes use of the fact that sometimes the resonant oscillations may be regarded to have two distinct components. The first of these is the "electrostatic" contribution calculated by Deering and Fejer; the second may be obtained from the cold plasma approximation and is generally smaller than the first one. The lower hybrid resonance is, however, an important exception from this rule; at an observation point that moves away from the point of excitation (across the magnetic field) with typical satellite or even rocket velocity, the "electrostatic" contribution must decay rapidly, since the group velocity of the constituent waves is less than the mean thermal velocity of ions. The cold plasma contribution is therefore under such circumstances the only one, and it is relatively easy to calculate. Expressions for the field of the lower hybrid resonant oscillations were derived in this manner. These expressions should be useful to experimenters who are planning the excitation of the lower hybrid resonance in the ionosphere from a rocket or satellite.

(b) Waves in a Warm Magnetoplasma

Many experiments performed in the ionosphere, to discover its properties, are based on the detection of a dispersive interaction of an electromagnetic field with the magnetoplasma medium in which the field exists. With few exceptions, it is common to plan such experiments so that a simple theoretical model will nearly describe the observed results. There are, however, numerous examples of so-called "anomalous results" that have occurred when the theoretical model has been too simple. A usual approximation is to assume the ionosphere to be a temperate magnetoplasma, and hence to ignore electro-acoustic effects. This approximation leads to the anticipation of various resonant conditions, but it does not reliably describe the observations made near such resonances, because it is there that the temperate plasma approximation is not valid.

A more complete treatment of waves of a magnetoplasma must account for the finite temperature and pressure of the electrons, and, perhaps ions as well. Some work has been done in this area. However, the results are, in general, in relatively unusable forms. Present efforts by Dr. R. R. Hodges at SCAS are being directed toward the development of a more useful formalism for the theory of waves in a warm magnetoplasma. This is to be applied in furthering the understanding of such phenomena as the Z-trace, scattering from ionospheric inhomogeneities, thermal noise fields in a magnetoplasma at nonpropagating frequencies, and the behavior of the impedance of an antenna in the ionosphere.

(c) Laboratory Plasmas

In many ways the ionosphere provides the best laboratory for plasma experiments, but the number of experiments that can be performed is limited by considerations of cost and convenience. This disadvantage can be alleviated by carrying out related measurements in the laboratory. Plasma with parameters typical of ionospheric conditions can be produced in the laboratory, and some types of probe experiments can be carried out. The laboratory measurements may suffer from inaccuracies due to the finite size of the vacuum chamber, and to uncertainties and non-uniformities in the plasma properties; nevertheless, even qualitative laboratory studies can help in the planning and design of rocket experiments and in the analysis and interpretation of the data.

A vacuum system specifically designed for plasma studies has been placed in operation at the SCAS by Drs. W. J. Heikkila and F. N. Holmquist and Mr. W. D. Bunting. Techniques and instrumentation developed for rocket experiments are being adapted to plasma studies using the chamber, with the support of NASA Grant NGR-44-004-030. The dependence of the high-frequency capacitance of a capacitor with a plasma dielectric on the measurement frequency is sensitive to the dependence of the electron collision frequency ν on the electron energy. In the Appleton-Hartree theory (Ratcliffe, 1959), it is assumed that ν is a constant, but observations indicate that this assumption is not satisfied. Other theories (for example, Sen and Wyller, 1960) incorporate a dependence of ν on energy. A high frequency capacitance probe has been instrumented using electronic components similar to those used in the rocket program under Contract No. NSR-44-004-017 and a coaxial capacitor using the vacuum chamber as the outer electrode. This system is being checked out at the present time. Some preliminary plasma measurements have been made utilizing a standard laboratory instrument for capacitance measurements in the 1 to 20 megacycle range. The initial observations indicate that the plasma frequency can be adjusted to occur within this range, and that the prospects for collision frequency measurements, therefore, appear to be reasonably good.

Langmuir probes are widely used for ionospheric studies. The interpretation of the measurements in the D region is open to question for two basic reasons. First, the several theories of electrostatic probes are based on the two extreme assumptions of collisionless and collision-dominated plasmas, whereas the electron collision frequency in the ionosphere is a strong function of altitude, and may have some intermediate value at a particular region. Secondly, the high vehicle velocity introduces violent flow effects on the ion sheath about the probe, particularly in the D region, where diffusion and drift velocities are small because of the short mean free paths. A proposal entitled "Laboratory Tests of Electrostatic Probe Theories" has been submitted to NASA to study these effects in the laboratory.

5. Geomagnetic Rapid Variations

Since June, 1964, the Southwest Center for Advanced Studies of the Graduate Research Center of the Southwest, under grants NSF GP-2907 and then GP-4339, has conducted a balanced theoretical and experimental study of magnetohydrodynamic (MHD) pulsations of the earth's magnetic and electric fields at the Dallas Hydromagnetic Observatory. The observational program is directed by A. W. Green, the analysis program by Dr. A. A. J. Hoffman, and the theoretical program by Dr. J. A. Fejer. Emphasis during the first year was on establishing the experimental program. As a result, the data acquisition system is substantially complete. In its present configuration, this observatory represents one of the most advanced facilities of its kind in the world. Since January, 1965 continuous recordings have been made on standard 1/2-inch magnetic tape and on two kinds of reproducible paper charts of the North-South and East-West horizontal components of both the earth's magnetic and electric fields in a frequency band from 0.01 to 2.0 cps. By means of data conditioning ("pre-whitening"), and "inverse-filter" computer routines, the useful frequency range is extended another two decades to approximately 0.0001 cps.

The magnetic field component measurements are made with mu-metal core coils, and the electric field measurements are made by means of electrodes buried in the earth and connected to high impedance amplifiers. This information, as well as time information, is recorded in analog form on a very slow magnetic tape unit. At the observatory site, selected magnetic tape records are played back at 20 times real-time, digitized, and re-recorded on IBM capatible digital magnetic tape.

At this time, program efforts are being directed toward characterizing the behavior of these MHD wave-derived "micropulsations" of the earth's electromagnetic field. By means of digital computers at the Graduate Research Center and Texas Christian University, these micropulsations are being characterized with regard to:

1. Variation of power spectral density with time of day,

2. Variation of wave polarization with time of day,

3. Possible correspondence of some classes of phenomena with solar wind velocity and magnetic activity indices,

4. Spatial coherence.

This preliminary characterization will be used to formulate first-order physical models for the generation and propagation of these waves. Additional data will be used for validation and refinement of these first physical models.

Plans are also being made to establish cooperative observation programs with other facilities in the United States and Europe and with the Borok and Tadjikistan Observatories of the Soviet Institute of Physics of the Earth. It is the purpose of these experiments to determine the degree of correlation of Pc and Pi type pulsations over large distances, as a function of station position relative to the earth-sun line. Because of the uniquely quiet background conditions which will be obtained for about the next year, the experiments are able to embrace the full range of micropulsation phenomena, including the very low amplitude "pearl," or Pc-1, events.

The range of frequencies covered in the program has recently been extended by the installation of a Rubidium vapor magnetometer system. This unit, the "ASMO," which is operated by the U. S. Coast and Geodetic Survey, provides a punched paper tape output each minute from which may be computed the D, H, and Z components of the earth's magnetic field. This is equivalent to having a standard magnetogram in digital form with sample values each minute. In this way a range from 0 to 10^{-2} cps is covered with a sensitivity of about 0.2 gamma.

Figure 5 shows a block diagram of the data gathering scheme now

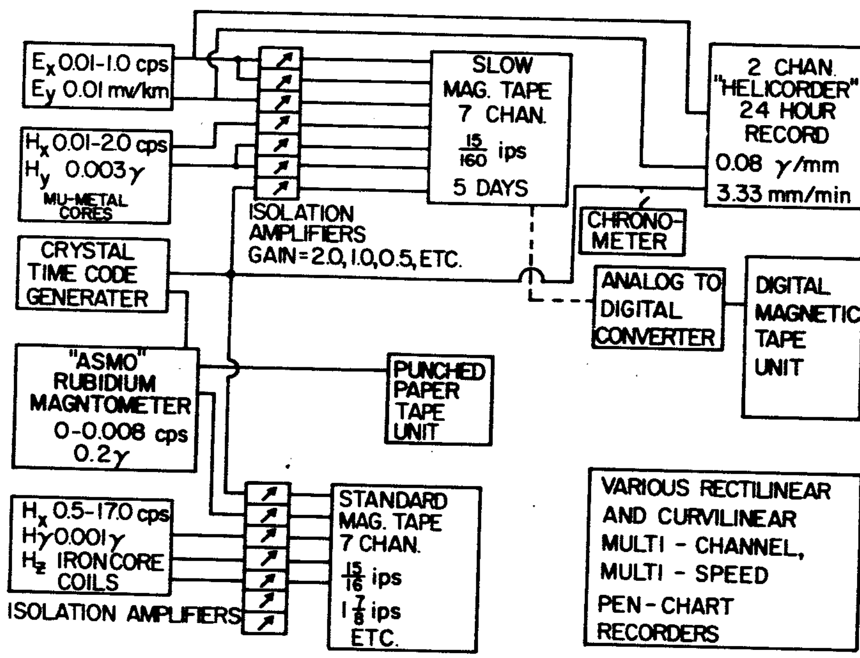

Figure 5 - Data gathering scheme at Dallas Observatory

in use at the experimental facility. The sensitivites and frequency ranges of each sensor are also noted on the diagram. (The subscripts, x and y used with H and E denote, respectively, N-S and E-W horizontal fields.) Figure 6 shows one of the special 6 foot long mu-metal core coils used to sense very long period waves (10^{0}-10^{-4} cps) along with one of the high frequency coils (10^{0}-10^{1} cps).

Figure 7 is illustrative of one type of characterization now being carried out, where the power spectral densities are shown for the N-S horizontal magnetic field on 1, 2, and 3 May, 1965, respectively, for

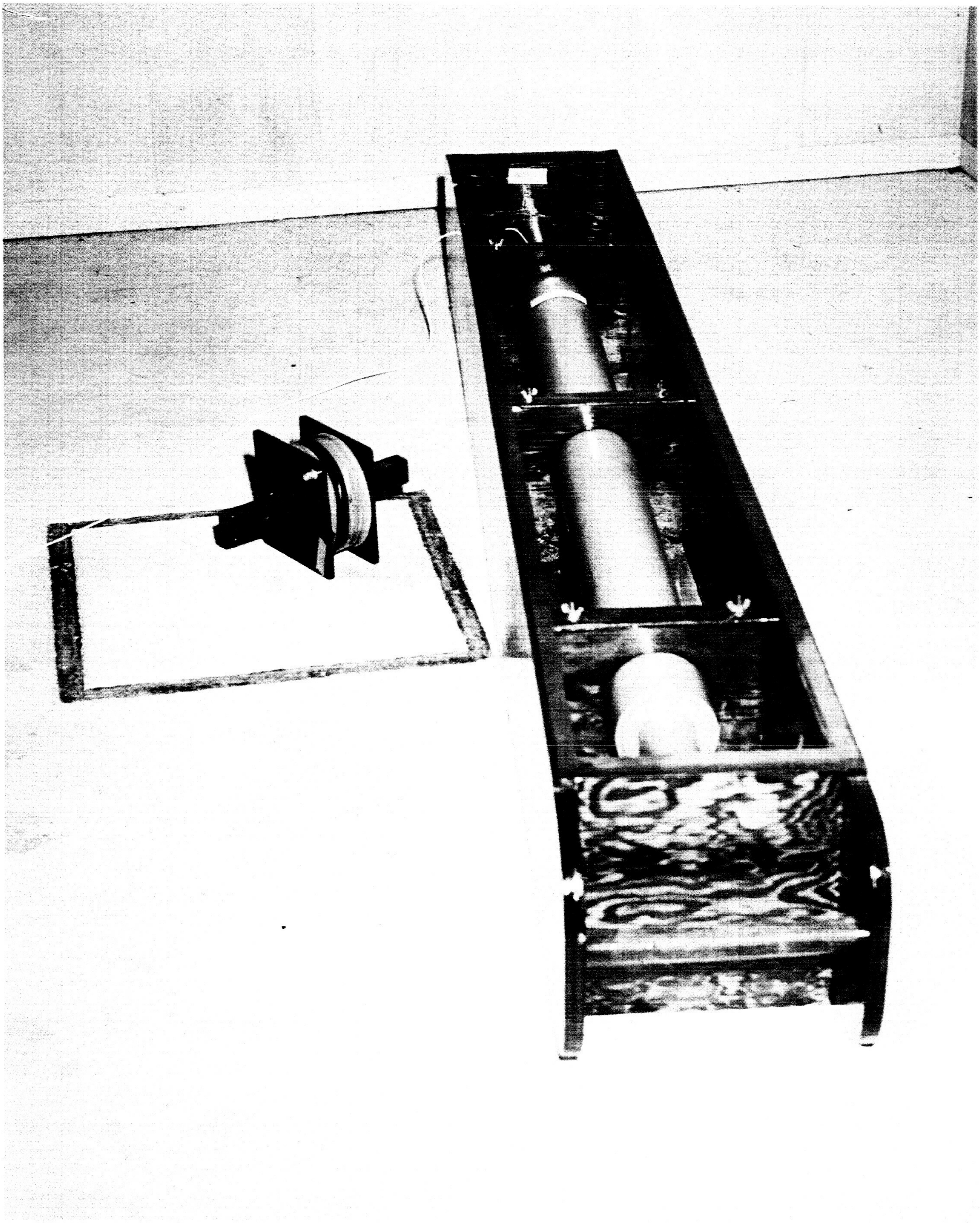

Figure 6

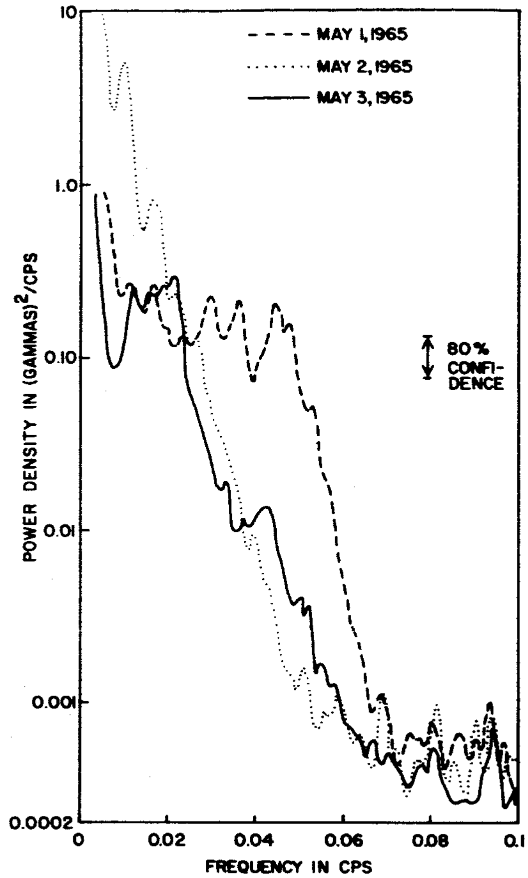

Figure 7 - Power Density vs. Frequency N-S Magnetic Field, Dallas Magnetic Observatory

the time interval from 1200-1500 CST. The prominent shelf-like features on the power spectra for 1 and 2 May are produced by the normal daytime Pc activity, which usually takes the form of trains of fairly monochromatic pulsations having periods in the 20 to 50 second range. Careful visual inspection of the pulsations recorded on 2 May reveals the presence of higher frequency components (often called "riders" in the literature), as well as lower frequency components; these combine to give the pulsations on this day a somewhat "ragged" or "irregular" appearance. Such pulsations are termed "Pi" (or irregular pulsations) in the literature. The different character of the 2 May pulsations is readily seen in the power spectrum for that day as evidenced by the "washing-out" of the "shelf" feature, the steeper slope, and the overall increase in power at all frequencies.

Although the characterization task has just begun, preliminary results indicate that such computer-based analysis will permit a more rigorous quantification of the micropulsation field behavior than has previously been obtained by the highly subjective visual inspection methods used in the past. The economy involved in making computer tapes at the observatory permits sufficiently long data runs and enough intervals for the compilation of meaningful statistics regarding field behavior.

6. Energetic Particles

(a) Neutron Monitors

There is a continuing program of operation of two large IQSY neutron monitors, one at Fort Churchill, Manitoba, the other at Dallas. These monitors constitute a portion of a world-wide network established at the start of the IQSY to permit resolution of the hour-to-hour changes in the cosmic ray flux of energy $>$ 1 Bev. The Fort Churchill monitor is also used by a number of other scientific groups as a source of quick-access data to choose suitable times to launch balloon-borne experiments to study cosmic ray phenomena. In this respect, the monitor is considered to be a portion of the range support equipment at the Churchill research range.

The neutron data are circulated, on a regular basis, to scientific workers throughout the world. They are also routinely reported in the CRPL monthly reports "Geomagnetic Data."

Extensive studies have been performed of the periodicities evident in the neutron data from the SCAS observatories, and elsewhere. Using numerical filtration techniques, a thorough study of the semi-diurnal variations (12-hour periodicity) during the years 1957-1965 has been made, and it has been shown that the various observations are consistent with an anisotropy of amplitude about 10^{-3} of the isotropic cosmic ray flux, the maximum flux arriving from directions at right angles to the interplanetary lines of force.

Extensive analysis of the diurnal (24-hour periodicity) variation in the cosmic radiation has shown that the observations are in impressive agreement with a theoretical model which predicts that the cosmic rays co-rotate round the sun - that is, they exhibit an angular velocity of drift around the sun equal to that of the sun itself. Theoretical studies of this subject have led to the prediction of a semiannual amplitude modulation of the diurnal variation. This subject is currently under study.

Computations of the deflections suffered by cosmic rays in the geomagnetic field have been performed using a simulation of the geomagnetic field including spherical harmonics up to the sixth degree in the field of internal origin; the consequences of a model magnetosphere have also been explored. Extensive tabulations of cosmic ray trajectory and cut-off rigidity data have been published for 79 observing stations as a portion of the documentation for the IQSY (IQSY Notes #10).

This program is performed by Dr. K. G. McCracken, Dr. U. R. Rao, and Mr. J. G. Ables, and is supported by NSF Grants GP-926 and GP-4688 and by AFCRL Contract AF 19(628)-5028.

(b) Balloon Program

(1) Fast Intensity Fluctuations

Balloon-borne instrumentation to study fluctuations of time scale equal to 1 minute or greater has been flown from Fort Churchill during the summers of 1964 and 1965. The detector cross-section is 0.36 m^2, and range measurements using scintillators separated by lead sheets provides data pertaining to the manner in which the fluctuations depend upon particle energy. These studies are being made by Mr. J. G. Ables.

(2) X-Ray Astronomy

Balloon flights have been made from Hyderabad, India, and Mildura, Australia, to search for X-rays in the wavelength range 0.3 to 0.8 Å from celestial objects. The detector consists of a scintillator, which is mounted behind a mechanical collimator, the "telescope" being inclined at an angle to the zenith, and being rotated about the vertical axis once every 10 minutes. In the first flight from Hyderabad (as part of the NSF balloon expedition to the equator), a source of X-rays was observed which is tentatively indentified with the object Cygnus XR-1, previously observed to emit X-rays in the 3-8 Å wavelength range. The data from the other flights is still being processed, and further flights using a telescope pointed at specific celestial objects is planned for October. This work is being performed by Drs. K. G. McCracken and P. J. Edwards.

(3) γ-Ray Astronomy

A spark chamber device to investigate celestial γ rays, or cosmic ray electrons, has been built, and is to be flown in late September from Palestine, Texas. In the γ-ray mode, the chamber is split into two sections, with a radiation length of lead between them. The observation of a positron-electron pair in the bottom chamber, unaccompanied by a track in the top chamber, permits identification of a γ-ray. Stereo photographs of the spark chamber permit identification of the direction of incidence of the γ-ray. This work is being pursued by Mr. E. Keath.

(4) Bremsstrahlung X-Rays

Balloon-borne equipment to study the X-rays generated by electrons precipitating into the auroral zone has been flown from Fort Churchill during the summer of 1964 and 1965. The 1965 flights were coordinated with the acquisition of data above Fort Churchill by the INJUN 4 satellite built by the State University of Iowa. This research is being pursued by Dr. K. G. McCracken and Dr. D. Venkatesan of SUI.

The balloon program is supported by NASA Contract NASr-198 and NASA Grant NsG-269-62.

(c) Satellite Instrumentation

Equipment to measure the degree of anisotropy of the cosmic radiation in the range 7.5 to 100 Mev/nucleon is to be flown on the deep space probes Pioneers A and B to be launched in late 1965 and early 1966. The first flight spacecraft is currently undergoing final tests in preparation for shipment to Cape Kennedy.

An experiment to be flown on the Interplanetary Monitoring Platforms F and G (launch 1966) is currently being built at SCAS. The experiment measures the degree of anisotropy, and the energy spectra of cosmic rays in the energy range 1 to 100 Mev generated in solar flares. The prototype instrument has successfully completed its first inspection at Goddard Space Flight Center, and is due for final delivery in November.

Both the Pioneer and IMP programs are directed towards an understanding of the manner in which cosmic rays are influenced by the magnetic fields in the solar system. Of particular interest is the diffusion of the cosmic rays through the irregularities in the interplanetary magnetic fields: the irregularities being due to turbulence in the solar plasma. The spacecraft experiments are being performed by Dr. K. G. McCracken, Dr. U. R. Rao, Dr. R. Bukata, and Mr. W. C. Bartley. The Pioneer experiment is funded by NASA Contract NAS2-1756, the IMP experiment by NASA Contract NAS5-9075.

(d) ISIS The Soft Particle Spectrometer

A soft particle spectrometer is being developed for the ISIS-A satellite under NASA Contract NAS5-9112. A breadboard instrument was completed and tested during the first half of 1965. The construction of an engineering model (required for radio interference testing) was begun during midsummer, 1965. This engineering model is now approaching completion and will undergo thorough testing during the remaining quarter of this year, before delivery which is scheduled for January, 1966. This program is directed by Dr. W. J. Heikkila.

7. Auroral Current Systems

Dr. J. A. Fejer is working on an extension of previous attempts (Fejer, 1963 and 1965) to explain the so-called auroral electrojets, the ionospheric currents that flow in an east-west direction in the auroral zones and are believed to cause the large magnetic disturbances at auroral latitudes. That explanation invoked the trapped energetic protons that have been observed with the aid of the Explorer 12 satellite by Davis and Williamson (1962). The protons were assumed to interact with low energy plasma co-rotation with the earth; the resulting charge separation led to currents along the magnetospheric field lines and in the ionosphere.

One difficulty with this explanation is the relative constancy of the energetic proton fluxes observed by Davis and Williamson. A way out of this difficulty can be found by invoking the energetic particles in the magnetospheric tail. There is both theoretical (Dessler, 1964; Fejer, 1965; and Wentworth, 1965) and observational (Ness, 1965) support for the idea that solar wind particles can enter the magnetospheric tail along a neutral sheet. In those regions where co-rotating low energy plasma is also present, and where the energetic particles of the neutral sheet are predominantly of one sign, charge separation can lead, as before, to auroral current systems if the ionospheric conductivity is high enough. If the conductivity were insufficiently high then electric polarization fields would build up and these in turn would modify the co-rotation of the low energy plasma in such a way that a field line would not cross over from the "closed" part of the magnetosphere into the "open" tail or vice versa. One consequence would be a diurnal change of magnetic latitude of low energy plasma at subauroral latitudes; whistler observations (Carpenter, 1965) appear to confirm the presence of such a diurnal change in the magnetic latitude of whistler ducts.

Previous numerical calculations of auroral current systems (Fejer, 1964) are also being extended by Drs. J. A. Fejer and B. Gottlieb, using enhanced electron concentrations in the auroral zone. Preliminary results indicate that these calculations will clearly define the high energy particle space charge densities and the auroral zone conductivities required to explain the observed magnetic disturbances by the mechanism considered.

8. Planetary Atmospheres

There has been a continuing interest at SCAS in the atmospheres of the planets, although little effort has been expended on this since the available data have been so sparse in the past. Mariner IV data (Kliori et al., 1965) have, however, made consideration of the Martian atmosphere much less speculative. Drs. F. S. Johnson and W. B. Hanson have interpreted the ionospheric data obtained at occultation in terms of atmospheric properties. The conclusion is that the atmosphere is exceedingly cold and that there is no thermosphere.

The lack of a thermosphere on Mars is to be associated with the large proportion of carbon dioxide that is present in the atmosphere. A thermosphere has developed in the earth's atmosphere because the principal atmospheric constituents are poor radiators in the infrared; the extreme ultraviolet solar radiation that is absorbed at high altitudes heats the atmosphere, and at that same altitude, infrared cooling is negligible. Consequently the temperature rises until some other physical process becomes effective in removing the heat; that is, the temperature rises until the temperature gradient becomes so steep that molecular conduction removes the heat by downward conduction into a region where there are enough infrared emitters to dissipate the heat. On Mars, the temperature rise is unnecessary, because the infrared emitters, in the form of carbon dioxide molecules, are plentiful in the ionospheric region where ultraviolet heating of the atmosphere is effective. On this account, a thermosphere on Mars is not to be expected.

The low average temperature derived for the Martian atmosphere brings one to the problem of precipitation of the carbon dioxide as dry ice. This can be avoided with the low temperatures that are required for the interpretation of the ionospheric data only by having the temperature distribution follow along the sublimation curve through most of the atmosphere up to 100 km. This situation can be expected to occur only if there is some physical process involving the sublimation vapor pressure that controls the temperature; it is not too difficult to imagine that such a process does exist.

This interpretation of the ionospheric data requires an atmosphere that is so cold that the water vapor content could not be as large as the number put forth on the basis of spectroscopic observations (Kaplan et al., 1964); the total water could not exceed about 2×10^{-4} g/cm^2, whereas a content of $(14 \pm 7) \times 10^{-4}$ g/cm^2 was claimed on the basis of the spectroscopic observations.

9. Interplanetary Physics

The interplanetary medium is dominated by the solar wind, a tenuous plasma expanding outward from the solar corona at supersonic speed. Since direct measurements of the properties of this medium at one astronomical unit are now available, it has become practical to begin to study theoretically the behavior of this plasma as it flows through the outer parts of the solar system. Therefore, based on earlier work of Patterson, Johnson, and Hanson, a study has been undertaken concerning the interaction of the solar wind with the interstellar medium.

This interaction takes place at a few tens of A.U. (astronomical units) or less from the sun. Upon encountering the interstellar gas and magnetic field, the supersonic solar wind undergoes a shock transition to subsonic flow. In the shock transition the gas may be heated to several million degrees. The solar wind thus carves out a cavity in the interstellar medium, a standing shock wave being separated from the cold interstellar medium by a shell of hot, slowly expanding, solar plasma. Given the density, velocity, etc. of the solar wind at 1 A.U. the solar wind theory (Parker) is used to predict the conditions on the near side of the shock, and the theory of a magnetohydrodynamic shock (deHoffman - Teller) is used to predict the conditions on the far side. The flow of the hot, magnetized plasma on the far side of the shock is studied with the use of the magnetohydrodynamic equations. The plasma interacts with the interstellar gas, a fraction of which is neutral hydrogen. Charge exchange reactions convert hot ions into high velocity atoms which promptly escape from the hot plasma, cooling it. The cooling radically affects the flow, decelerating it and thereby compressing the plasma. The magnetic field carried by the plasma also plays an important role in the dynamics.

The temperature, density, and flow velocity distributions are computed for a range of initial conditions as well as interstellar conditions. The flux of hot atoms leaving the shell is also computed. These atoms traverse the inner solar system on ballistic orbits, and can be observed by virtue of the solar ultraviolet (Lyman-alpha) radiation which they scatter. Such observations indicate that there must be $\sim 2 \times 10^{-2}$ fast hydrogen atoms/cm^3 near 1 A.U. This figure permits a normalization of the computation of the fast atom flux, yielding finally the heliocentric distance to the shock.

For a wide range of interstellar densities (10^{-2} to 10 atoms/cm^3), the shock radius falls in the range $\sim$5-20 A.U. The thickness of the hot plasma shell is found to be of the order of the shock radius.

Related studies of neutral interplanetary hydrogen originating at the sun and by neutralization of solar wind through collisions with interplanetary dust have been made, as well as studies of the interaction of the solar wind with cosmic rays.

The solar wind-interstellar medium interaction makes itself felt near the earth in a number of observable phenomena, e.g. the interplanetary neutral hydrogen atoms and the modulation of cosmic radiation. The possibility therefore arises of using these very local phenomena as indirect probes of the (as yet inaccessible) interstellar medium. For example, the present analysis concludes that the interstellar magnetic field in this part of the galaxy must be stronger than 2 x 10^{-5} gauss and the density of neutral hydrogen must be greater than about 10^{-2} atoms/cm^3

This program was carried out by Dr. A. M. Lenchek, supported by NASA.

10. Atmospheric Chemistry

(a) Reaction Kinetics

Quantitative knowledge of the sources of the chemically and electronically unstable species observed in the atmosphere, as well as the mechanisms resulting in their eventual destruction, is of extreme importance in the construction and understanding of detailed atmospheric models. Although the current stage of technological development precludes measurement under simulated atmospheric conditions, experiments conducted at measureably high concentrations can be extrapolated back to atmospheric conditions provided the detailed microstructure of the reactions is sufficiently well known. For this reason the laboratory program in reaction kinetics, established at SCAS by Drs. C. B. Collins and W. B. Hurt during the past year, has been concerned not only with the rates of chemical and ionic reactions of atmospheric importance, but also with an extensive investigation into the details of the reactions in an attempt to develop sufficient knowledge to permit the construction of a detailed reaction model from which, for instance, the dependence of reaction rate on concentration and temperature might be inferred.

One such project under continuing investigation is a study of ion-electron recombination mechanisms in flowing afterglows. Of particular interest is the measurement of dissociative recombination by which a molecular ion recombines with an electron, subsequently dissociating into an electronically excited atom and one or more normal atoms. Such recombination provides the dominant neutralization process for atmospheric ions. However, attempts to measure such rates in the laboratory have been few and often have the generally unrecognized complication that other unwanted ion-electron recombination processes can contribute to the measured rates. One such example is found in the helium afterglow. The measured rates of electron-ion recombination were for many years identified as pertaining to dissociative recombination of He_2^+. However, more recent investigations into the detailed steps of the recombination have shown that the dominant recombination in helium under laboratory conditions is definitely not dissociative. Continuing studies in this laboratory have confirmed that, in fact, the observed rates of production of excited atoms as a result of ion-electron recombination in helium is in complete contradiction with every currently accepted theory for such processes (Collins, 1965a).

A theoretical investigation into a newly studied recombination mechanism, collisional-dissociative recombination, has shown that ions of molecules having repulsive neutral states not "crossing" the ionic potential curve can recombine with electrons by this mechanism with rate coefficients as large as

$$\alpha = \frac{g_o}{2g^+} A_D \left(\frac{2\pi mKT_e}{h^3}\right)^{-3/2} ,$$

where g_o and g^+ are the electronic degeneracies of the molecular ion and neutral repulsive states, A_D is the rate coefficient for spontaneous dissociation, m is the electron mass, T_e, the electron temperature, and the other terms have conventional meanings (Collins, 1965b). Although no example of this process has yet been identified, these theoretical studies have shown that in certain circumstances such a process could occur in the laboratory and be mistaken for dissociative recombination. Reaction rates measured under these conditions could not be extrapolated to atmospheric conditions without the possibility of gross error. Investigations have been initiated to attempt to positively identify such a collisional-dissociative recombination. Preliminary results indicate that this process may occur in laboratory helium afterglows, being partially responsible for the anomalous ion-electron recombination effects discussed above.

Although helium is a relatively minor atmospheric constituent, by virtue of the fact that it produces the simplest plasma for laboratory study and has been the object of the most extensive previous investigations, further investigations into the reaction kinetics associated with the various energy-carrying species produced in helium are being continued while studies in the much more complex gases, such as nitrogen and oxygen, are being initiated.

A recent feasibility study has shown that analysis of the spatial extent of visible radiation from a dc discharge can also be a powerful tool for the measurement of ion-molecule reaction rates as well as ion-electron recombination coefficients over a wide range of temperatures, once the detailed path of the reactions is known. Commencing with assumed reaction rates, the spatial distributions of the radiations of various wavelengths expected from a dc discharge are synthesized by a C.D.C. 3400 computer. Subsequently repetitions of the calculations are made, each with slightly different assumed rates, until the distributions actually observed are reproduced. It has been found that the theoretical distribution best fitting observation is both unique and highly sensitive to the assumed rates, strongly indicating that the assumed rates are valid approximations to the real reaction rates at the particular values of concentration and temperature existing in the discharge.

Figure 8 shows a comparison of an experimentally observed distribution of radiation from helium atoms (solid curve on left) and helium molecules (solid curve on right) as functions of lineal distance from the cathode of a dc discharge in pure helium in the ten Torr pressure range. Shown for comparison are the synthesized curves calculated from a model in which production of excited species by inelastic collisions with

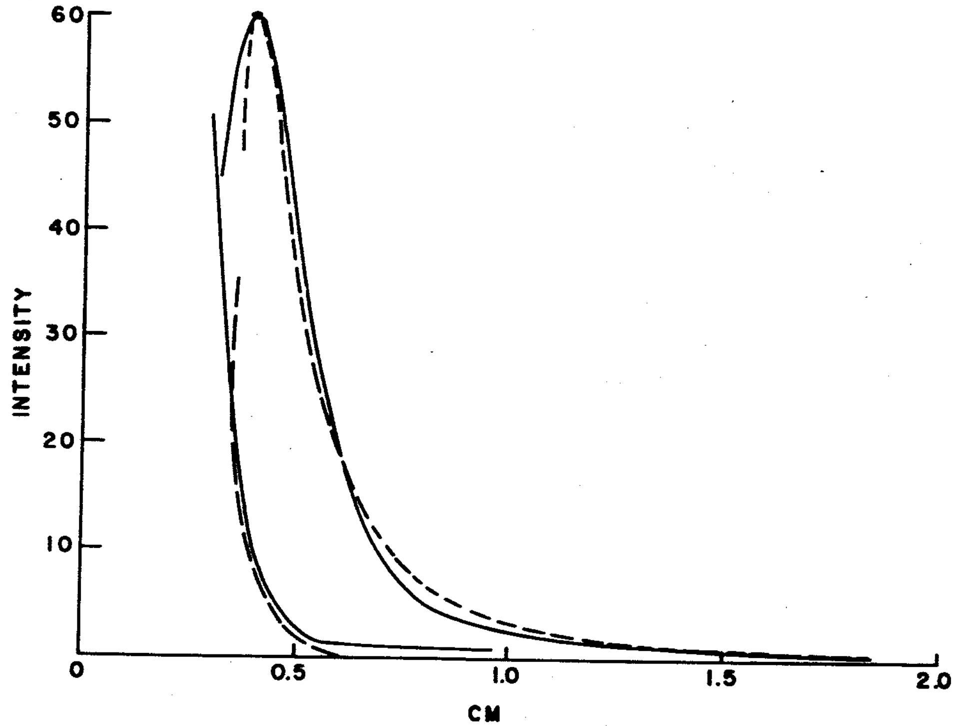

Figure 8 - Dashed curves show the theoretical spatial distributions of atomic and molecular emission, further refined with the inclusion of a source of ionization resulting from collisions of metastable atoms. Solid curves show comparable measured distributions.

energetic electrons is confined to within a millimeter of the cathode. These species, principally He^+ at this distance, are considered to diffuse away from the cathode into the field-free negative glow while undergoing either conversion to He_2^+ or recombination with free electrons into radiating states of the neutral atom. The He_2^+ ions so formed also are assumed to recombine with electrons to yield the states radiating the observed molecular bands.

The introduction of about 4% nitrogen to the discharge provides a third alternative loss for the He^+, that of destruction via the ion-molecule reaction

$$He^+ + N_2 \rightarrow (N_2^+)^* + He$$

$$\text{or} \quad He^+ + N_2 \rightarrow N^+ + N + He,$$

where the asterisk denotes a freely radiating state. Figure 9 presents the observed distribution of He^+, which is in complete agreement with the modified model provided the rate of the reaction is approximately 3×10^{-12} cm^3/sec. The observed distribution of (N_2^+)* appears to follow the He^+ concentration as a function of distance from the cathode, which suggests that it indeed results from reaction (1).

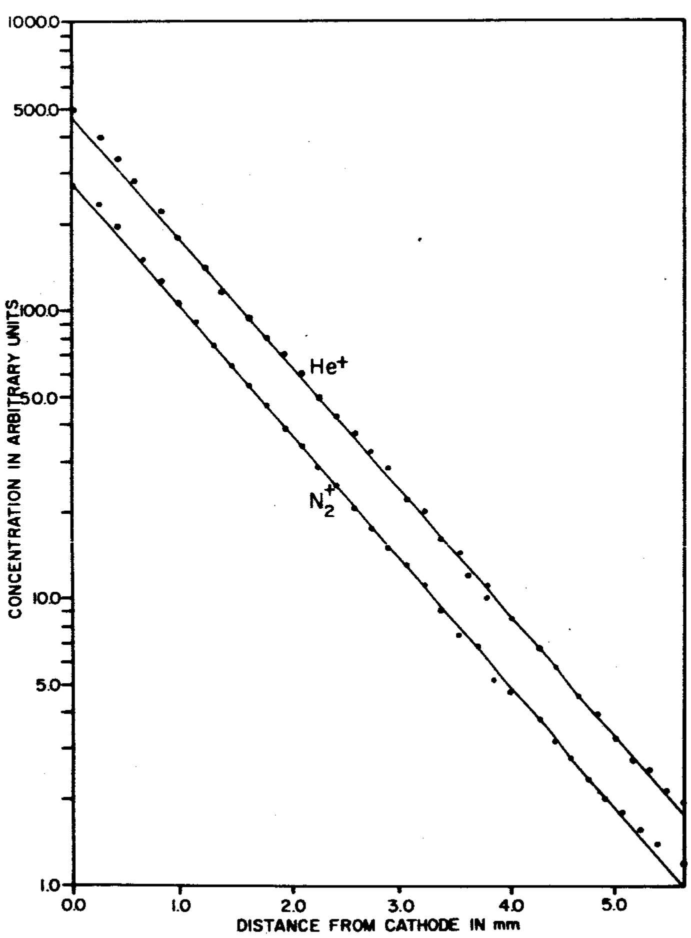

Figure 9 - A comparison of the concentration of He^+ and N_2^+ as deduced from spectroscopic data taken on a negative glow in a 2% nitrogen in helium mixture at 750°K.

The rate of this reaction is of critical importance to the maintenance of helium ions in the ionosphere, and the value measured here agrees well with values deduced from atmospheric considerations but disagrees with previous laboratory measurements (Ferguson et al., 1964). Further examination of this reaction is planned, together with an extension of this highly promising method to other gas mixtures.

(b) Airglow

A grille spectrometer of very high speed has been built at SCAS by Dr. B. A. Tinsley. The instrument is now installed at a field location near the Irving Langmuir Laboratory near Socorro, New Mexico. This site has an altitude of 10,600 feet and an unobstructed sky view down to within 5^{o} of the horizon. The Langmuir Laboratory, which is operated by the New Mexico Institute of Mining and Technology, provides accomodations for the observer and other supporting facilities.

Field operations have been confined so far to the observation of geocoronal $H\alpha$(6563Å) in the night sky, and HeI($^3P-^3S$) at 10,830Å in the morning and evening twilight. A set of $H\alpha$ observations covering the whole sky are made once per hour on every clear night when the moon is below the horizon. Observations have been made since May, 1965. Reduction of the results is still in an early stage, however, it is apparent that the emission is less concentrated in the plane of the ecliptic and toward the sun than was found by Sheglov in 1962-63. The present results confirm Sheglov's in that an average intensity somewhere around 10 Rayleighs is observed, whereas theoretical work by Donahue and others, based on Lyα intensities, predicts around 1 Rayleigh.

A limited number of zenith helium observations show, after correction for OH emissions, that the intensity is now at least a factor of 2 less than the 1000R reported by Soviet workers in 1961.

This program is supported by an NSF grant.

11. Infrared Studies

There is a theoretical infrared program at SCAS carried out by Dr. G. N. Plass. During the past six months, work in this field has been divided between studies of the interaction of electromagnetic radiation with absorbing particles such as are found in the atmosphere and studies of the absorption of laser radiation along atmospheric slant paths.

(a) Interaction of Electromagnetic Radiation with Absorbing Particles

The interaction of electromagnetic radiation with absorbing spheres has been studied by means of a particularly efficient computer program for the calculation of Mie scattering and absorption. The results of this study have many applications to absorbing particles in planetary atmospheres. Because of the complexity of the calculation, only very limited results from the Mie theory have been available until now for absorbing particles. We have systematically calculated the scattering and absorption cross sections for a wide range of indices of refraction. The results are given in detail in an article which has been accepted for publication by Applied Optics. Detailed results were obtained for $n_1 = 1.01$, 1.33, 1.5, 2, and $n_2 = 0$, 10^{-4}, 10^{-2}, 10^{-1}, 1, 10, where the index of refraction n is written $n = n_1 - in_2$. The influence of the absorption on the scattering was determined. The variation of the scattered intensity with angle as n_2 is varied was derived for some typical cases. Finally the influence of n_2 on the very narrow resonances in the absorption and scattering cross sections which occur for large values of n_1 was investigated. The general variation of any of the results of the Mie Theory with the amount of absorption in the particle can be determined from these results.

In a separate study the scattering and absorption cross sections for electromagnetic radiation incident upon spherical particles of aluminum oxide is calculated form the Mie Theory for a temperature range from 1200°C to 2020°C. Aluminum oxide is an important constituent of many rocket exhausts. Results based on the absorption coefficients of Gryvnak and Burch were obtained for particle radii from 0.1μ to 10μ and a range of wavelengths from 0.5μ to 6μ. At a wavelength of 2μ the efficiency factor for absorption increases by a factor of 40 as the temperature increases from 1200°C to 2020°C. A paper on this subject has been accepted for publication by Applied Optics.

(b) Absorption of Laser Radiation Along Atmospheric Slant Paths

The absorption of laser radiation along atmospheric slant paths has been studied when Lambert's law is valid. The Lorentz pressure broadened line shape was assumed for the atmospheric absorbing gases. Illustrative results have been obtained for absorbing gases which are distributed uniformly throughout the atmosphere and when the temperature variation of the line intensities and half-width can be neglected. These results were then generalized to include cases of non-uniformly distributed gases with a temperature variation along the path. The effect of the overlapping of the spectral lines was studied through the use of the Elsasser model. It was shown that large differences in the absorptance may occur between corresponding frequencies in the red and violet wings when there is a shift in the position of the line center with pressure. This line shift could ideally be studied with laser sources. The results are given in detail in an article which has been accepted for publication by Applied Optics.

The infrared program derives partial support from Air Force Cambridge Research Laboratories.

12. Lunar Investigations

(a) Surface Reflectivity

A study has been undertaken by Phil Oetking at SCAS on the photometric studies of diffusely reflecting surfaces. Further improvement in the test equipment has been accomplished, measurements on many more samples have been carried out in a variety of illuminating and detecting arrangements; this has confirmed our earlier laboratory findings of a sharp retrodirective peak in the reflection curve for almost all common materials.

The present study shows that one of the unusual photometric properties of the lunar surface, the abrupt rise in the reflection intensity at full moon, is not necessarily diagnostic in determining the nature of the lunar surface. Figure 10 shows the variation of lunar surface brightness with phase angle. Most substances reflect light in a similar manner when viewed under these same conditions as can be seen in Figure 11. The results obtained from the measurements of several hundred samples show that the light reflected from most surfaces is exceedingly angle-dependent near zero phase, i.e., when the angle of observation and the angle of illumination are nearly coincident. A surge in the intensity begins to occur a number of degrees before zero phase and the highest intensity develops as the detector

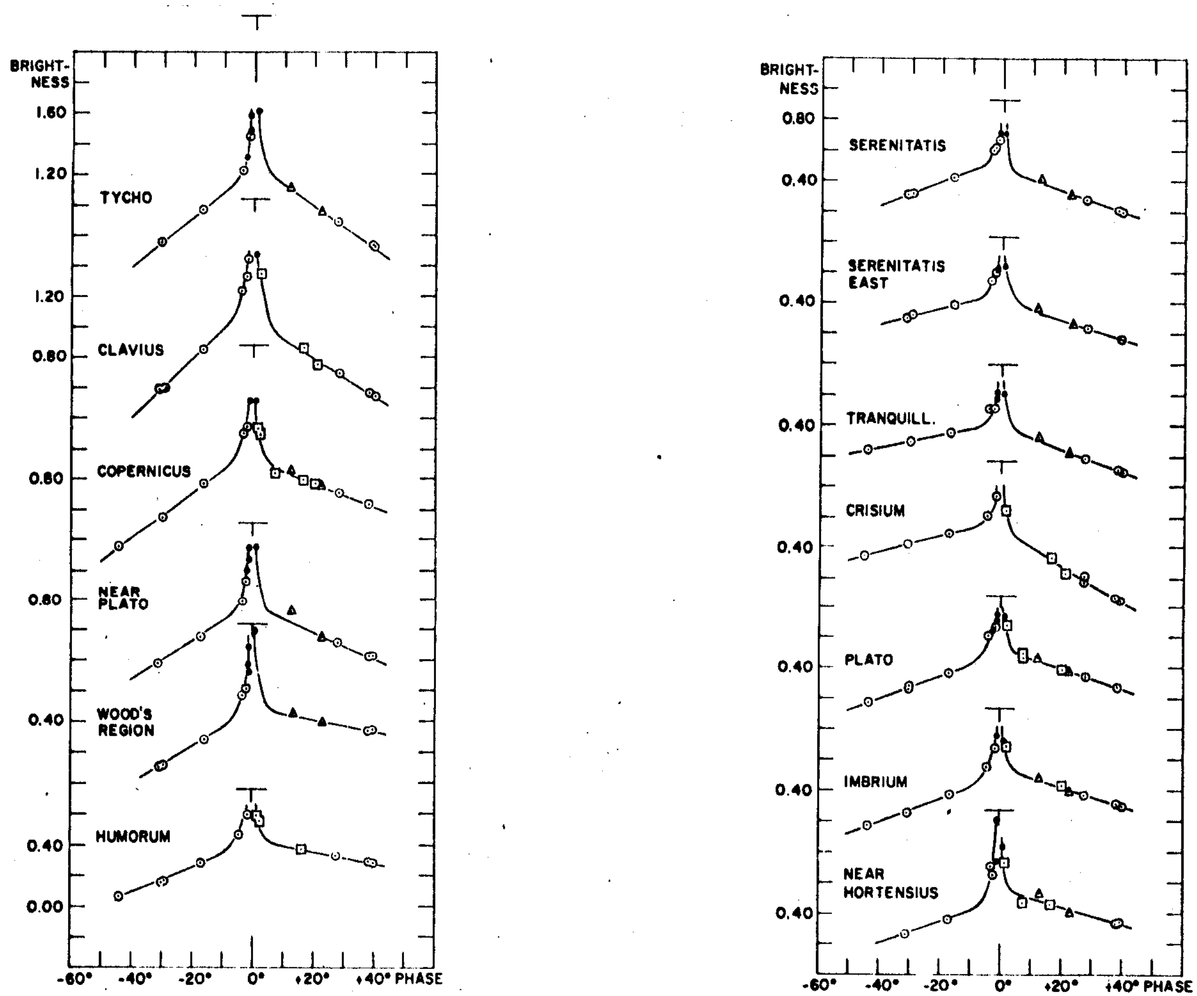

Fig. 10 Curves showing brightness as a function of phase for various lunar regions from observations of December 1963/January 1964; Gehrels, Coffeen, Owings (1964).

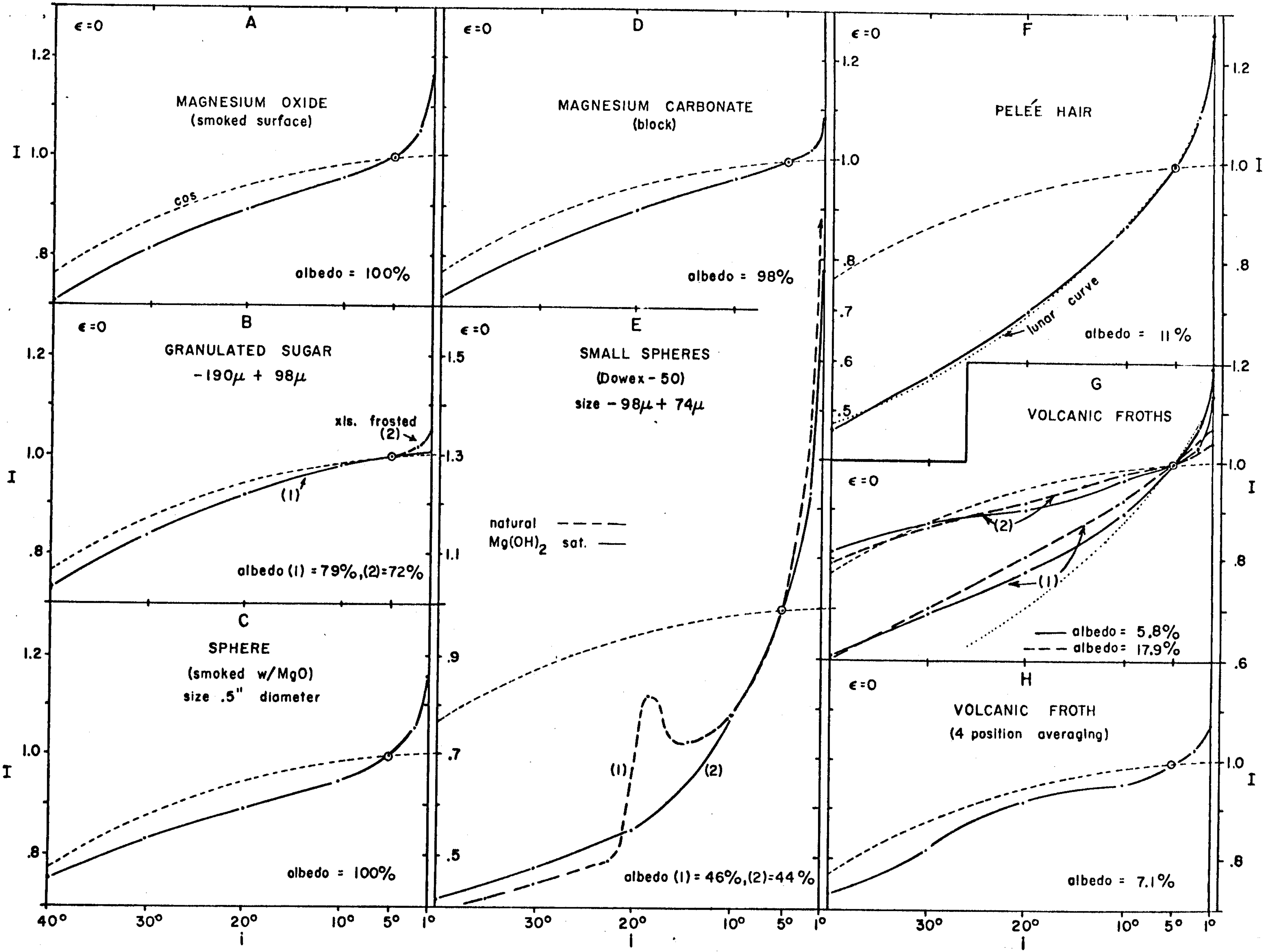

Fig. 11 Reflectivity curves of various materials

begins to occult the incident light beam, as indicated in Figures 12 and 13. A rise in the intensity of 15 to 20% is not unusual. The angular position of the initial intensity increases and the height of the "central peak" varies with the sample tested.

We are in the process of attempting to delineate the factors which control the shape and the percent rise of the central peak. Thus far, it appears that the peak is higher and more abrupt in translucent materials as the particle size of the sample is decreased. However, this effect is small if the particles are opaque, and it is interesting that both solid substances and loosely packed particles may show equally well developed intensity peaks, as can be seen in Figure 14. To date, none of the influencing factors is fully understood.

Studies of the dependence of reflectivity on illumination and viewing angles relative to the surface, on particle shape, size, and state of consolidation are being continued. Special emphasis is being placed on polarization and wave length investigations. Also, a series of experiments to determine the feasibility of using reflectivity properties of terrestrial materials as a basis for reconnaissance mapping is being examined. A manuscript entitled "Photometric studies of diffusely reflecting surfaces with applications to the brightness of the Moon" has been submitted to the Journal of Geophysical Research.

(b) Lunar Atmosphere

Dr. G. Riley has given some attention to the probable constituents of the lunar atmosphere and the geophysical significance of some of the constituents. Along with Dr. F. S. Johnson, he has considered the problem

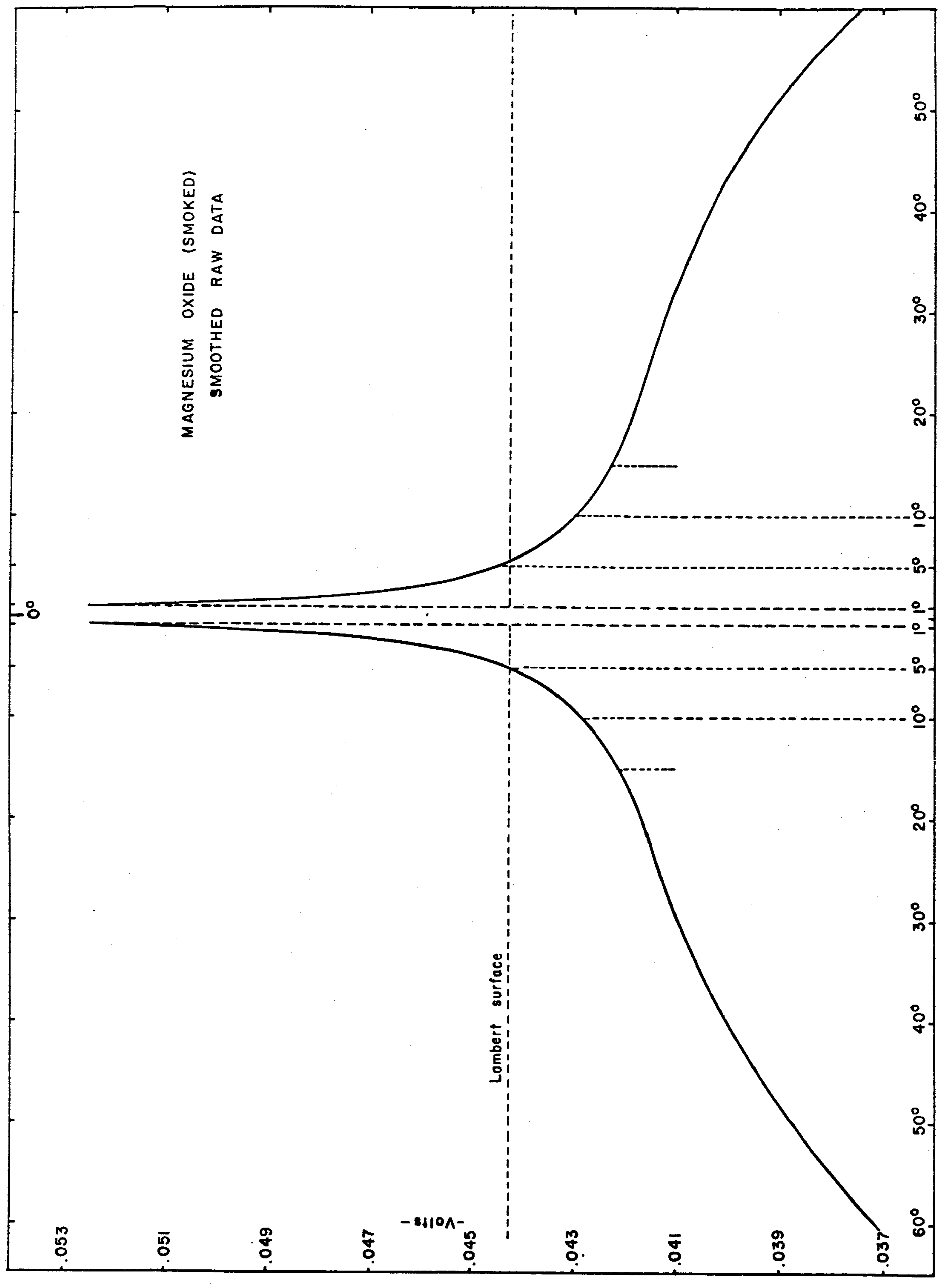
MAGNESIUM OXIDE (SMOKED)
SMOOTHED RAW DATA
Lambert surface
-Volts-
.053
.051
.049
.047
.045
.043
.041
.039
.037
0°
60°
50°
40°
30°
20°
10°
5°
1°
1°
5°
10°
20°
30°
40°
50°

Fig. 12

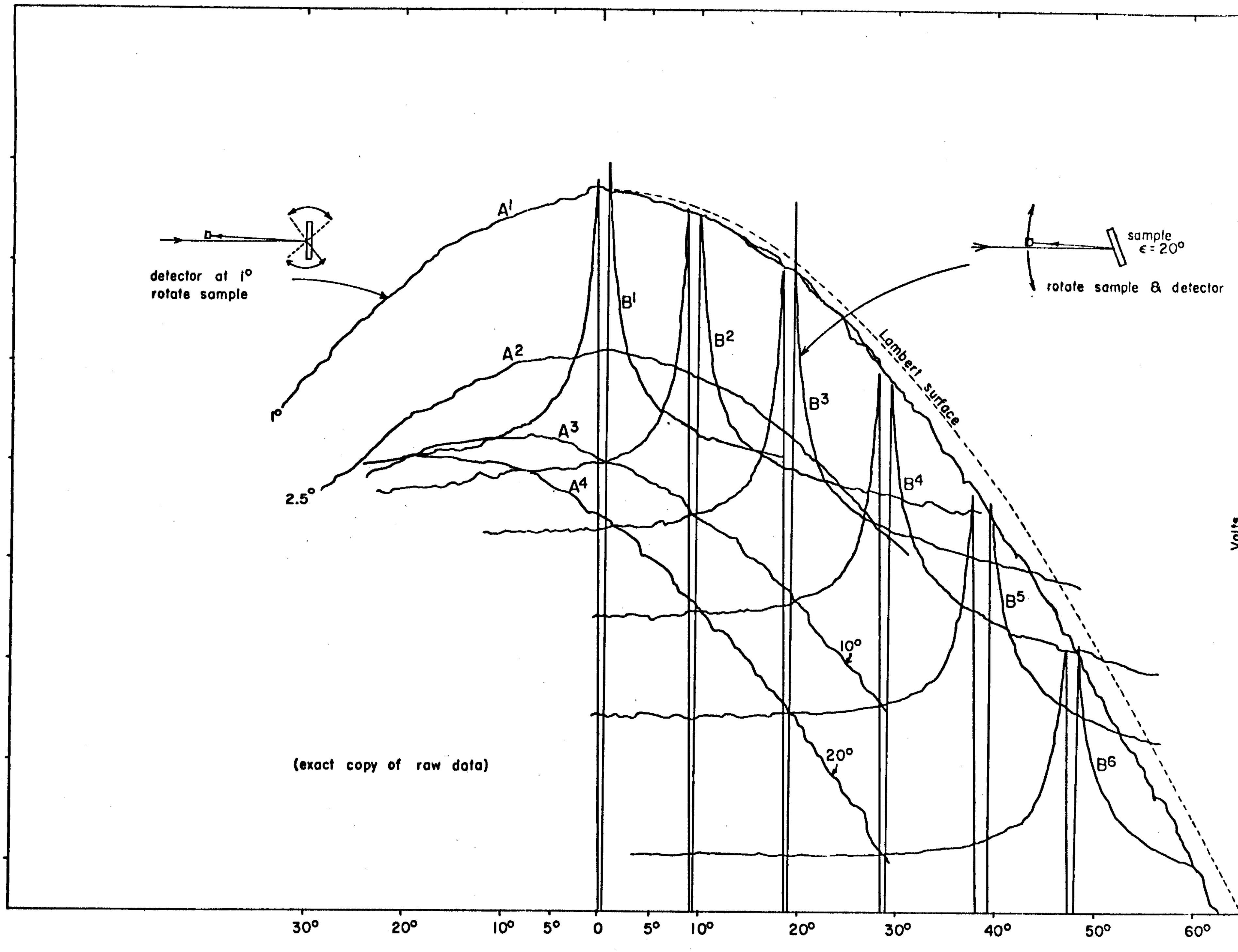

Fig. 13 Reflectivity curves of magnesium oxide

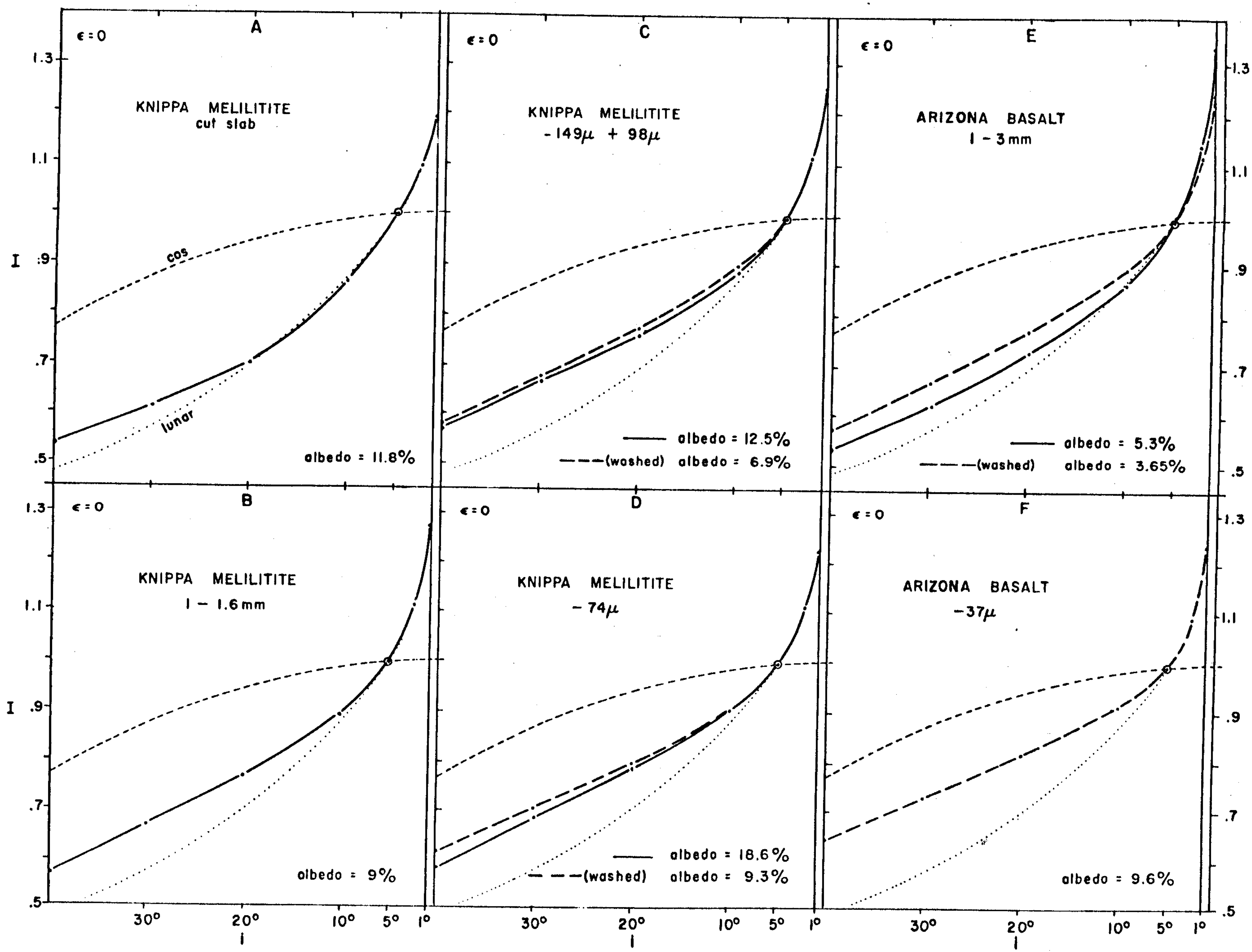

Fig. 14 Reflectivity curves of basic rocks

of measuring the lunar atmosphere. In particular, the suitability of coincidence mass spectrometer is being investigated. Because of the very low concentration of any lunar atmosphere, extreme sensitivity will be required to measure it, and digital techniques are surely required. The background of spurious counts can be markedly reduced by the coincidence feature of the coincidence mass spectrometer, which records an event as an ion only if the electron that was released in producing the ion is also observed. This work is being done under NASA Contract NAS9-4830 with Manned Spacecraft Center, Houston.

13. Geochemistry

(a) Geochronology

The geochronology program at SCAS is directed at answering questions of geological importance through the application of the techniques of isotope geochemistry.

(1) Lebombo Mountains, South Africa

Research has been directed towards the problem of the origin of the granitic magmas that are frequently found associated with equal or slightly greater volumes of basaltic magma. The two most plausible theories that are given serious consideration at the present time propose very different origins for them; the one claiming that they are formed by fusion of the granitic crust of the continents, the other postulating that they were derived from the earth's mantle only a short time before their extrusion. These theories are amenable to testing, because the crustal rocks have a far greater Rb/Sr ratio than those of the mantle. Consequently, magmas resulting from fusion of the crust would have higher content of radiogenic

Sr^{87} than those derived from the mantle.

Basalts, rhyolites, gabbros, and granites from the northern and southern ends of the 450 mile outcrop of the Lebombo Mountains, Southern Africa were chosen as an ideal suite for testing these hypotheses. Strontium isotopic composition runs were performed on the Center's 12" mass spectrometer. Rb and Sr concentrations have been measured by X-ray fluorescence, atomic absorption analysis, and isotope dilution.

At the southern end the basalts, rhyolites, and gramophyres had a common initial Sr^{87}/Sr^{86} ratio of 0.705 which is indicative of a mantle origin for both the basic and acid magmas. In the north, the basalts of the first main outpouring have initial ratios of 0.707, but the later rhyolites, basalts, gabbros, and granites all have initial ratios of 0.711, which would conventionally be interpreted as indicating a crustal origin. This paradox can be resolved if it is postulated that all the magmas were derived from the mantle in a series of differentiations and were isolated for a period of time before extrusion.

This work is being done by William Manton.

(2) The Half-Life of $Rubidium^{87}$

The precision of dating of rocks by the analysis of Rb^{87} and Sr^{87} is at present limited by the precision with which the decay constant of Rb^{87} is known. The aim of this project, which is under the direction of Dr. G. Riley, is a geologic comparison of the β-decay constants of Rb^{87} and K^{40}. Samples are available to determine the relative constancy of these decay constants over a wide range of geologic time and, eventually to improve the accuracy limits of the Rb^{87} half-life.

Because of the high abundance of Ca^{40} in nature, only those environments low in common calcium are feasible for K-Ca dating. Suites of samples from lithium-rich pegmatites in Canada and the U.S.A. have been collected and high purity mineral concentrates made. These samples have been analyzed for potassium, calcium, rubidium, and strontium by atomic absorption spectrophotometry to provide a guide for more precise determinations by stable isotope dilution. A six-inch solid source mass spectrometer has recently been completed for this latter purpose.

Identification and purity of all minerals analyzed is achieved by X-ray diffraction analysis.

(3) Rhenium-Osmium Studies

The aim of this project is to examine the feasibility of applying the β-decay Re^{187} to age determinations of rock systems. Because of the low ion emission of both Re and Os, high ion detection sensitivity in the mass spectrometer is necessary.

A 400-channel multiscaling system has been built and tested. The system will be used in conjunction with ion pulse-counting detection, followed by high speed (35 mc max.) scaling. Fast mass scans synchronized with the address register of the multiscaler will allow repetitive mass spectra of low ion densities to be accumulated and integrated in the memory. Accumulation is continued until any desired level of counting precision is attained.

This data accumulation system has sufficient flexibility to allow its application to precise measurement of much more intense ion beams. In this case, the ion beam is collected by conventional Faraday cup and amplified by a vibrating reed electrometer. This amplifier drives a 1 mc voltage-to-frequency-converter which then feeds the multiscaling system.

The data system is programable to allow simultaneous dual channel inputs which share the memory. Application of such a double collection system is expected to yield isotope ratios of higher precision than is possible at the present time. It will be used in the measurement of low enrichments of Ca^{40} from potassium β-decay.

This program is under the direction Dr. G. Riley.

(4) Geochemical Investigations of Ultrabasic Minerals and Rocks

Compositions of the surficial materials from planets and satellites are strongly dependent on the chemical compositions of planetary interiors and the processes operating therein. Clues as to the nature of the processes which have operated in the development of the bodies in the solar system can at present be found only in studies of meteorite material or on the one planet at present open to direct observation, namely, the earth. It is well established that the crust of the earth does not offer a representative sample of the material of which the earth was formed. The best samples currently available are the nodular inclusions of garnet-peridotite which occur in diamond pipes. The study of these samples of the mantle should be combined with experimental high pressure-high temperature studies of synthetic mineral assemblages which are related to those found in nature. Equipment for this study has now been assembled.

During the past six months, the results of an experimental study of the synthetic peridotite system MgO-CaO-Al_2O_3-SiO_2 have been analyzed and the stability field of the system has been defined. It is inferred that the spinel-bearing peridotites found at the earth's surface are not samples of the primary mantle. It is possible, however, that the garnet-bearing peridotites do represent primary mantle material and samples of the naturally occurring periodites are being collected for study.

This program is being carried out by Drs. B. T. C. Davis and I. D. McGregor.

14. Planetary Structure

During the period April - September 1965, Dr. M. Landisman, with the help of visiting scientists, presented oral reports to the Seismological Society of America in St. Louis, Missouri, and the Second International Symposium on Geophysical Theory and Computers in Rehovoth, Israel. Three papers related to the study of planetary interiors were submitted to the Geophysical Journal (R.A.S.).

As a result of the collaboration made possible by the visit of Professor Stephan Mueller, of the Technische Hochschule Karlsruhe, two papers were prepared which describe a newly discovered world-wide, low-velocity region in the sialic layer of the crust in continents and continental margins. This low-velocity zone, which lies just below the surface, accounts for: 1) strong secondary arrivals observed 30 to 100 km from the shot point in continental seismic refraction profiles; 2) well observed normal-incidence reflections from the abrupt velocity increase; 3) the ½ km/sec discrepancy in compressional velocities for the granitic layer as measured by earthquakes and explosions, since 4) the majority of carefully studied crustal shocks have focal depths that lie within the sialic low-velocity region. In addition it has been found that the delay between the refraction from the granitic basement, designated as P_g, and the arrival from the interface below the sialic low-velocity region, termed P_c, is proportional to the heat flow, wherever good measurements for both quantities are available.

This subject is now being further explored with the help of Visiting Professor Karl Fuchs. The region being studied lies in Central Germany extending southerly from a point somewhat south of Hannover past Ansbach. The lower crust in this region seems to be remarkably undisturbed, with layers that can be followed for perhaps as much as a few hundred kilometers. A well-developed P_c arrival and the sialic low-velocity zone have been found for this region.

The study of theoretical seismograms was advanced by the visit of Professor Yasuo Sato of the Earthquake Research Institute, the University of Tokyo. A preliminary study was made of the propagation of spheroidal disturbances in an earth whose velocities are specified by the studies of Gutenberg and whose density follows Bullen's model A'. This study produced fundamental mode seismograms which exhibit the well-known Airy phase with a period near 220 seconds. The period and group velocity in the theoretical seismograms is concordant with surface wave observations to within about 1%.

In addition, it has been possible to program a Stromberg-Carlson SC-4020 digital cathode-ray tube plotter to produce theoretical seismograms. This facility will be used in future studies.

These studies of planetary interiors, using data for the earth as an example, should help in the interpretation of seismic data which may be expected to be obtained for the Moon and inner planets in the next few years.

15. Paleomagnetism

As part of the efforts at SCAS to understand the development of the earth's crust, Dr. Helsley has continued his study of the magnetization of rocks from Africa (Helsley, 1965). Our initial collections from North Africa in the spring of 1964 contributed significantly to the polar wander path for Africa, but left some uncertainty as to how the pole had moved during the Upper Paleozoic (Upper Silurian to Carboniferous). A more or less continuous redbed sequence believed to span this time interval is present in Israel, although the age assignment within the sequence is very poor. This sequence was sampled, along with some Cenozoic and Mesozoic rocks, during the early part of the summer of 1965 and is currently being measured. Some of the results from the Cenozoic rocks (Late Tertiary) have yielded data that indicates a pole position for rocks of the Miocene age in the Central North Atlantic, a position previously reported by Cox (1957) and Torreason et al. (1949) from North America, but generally not believed since it is quite different from most Cenozoic results. Other samples from the same lava sequence, however, agree quite well with other Tertiary data from Africa.

Many of the samples collected this past summer as part of this study, as well as those for other studies currently underway in the laboratory, have magnetic moments very near the limits of detection of our present equipment. Thus, a considerable effort is currently going on in the lab and will continue for some months toward improving and adding to our instrumentation.

16. Kinetic Theory

Work proceeded on a general-relativistic kinetic theory of gases. We are motivated by the desire to obtain a model of matter in Einstein's theory of gravitation that seems more appropriate than that of continuum mechanics, for example in the description of stars, galaxies, and universes. This work was begun early this year and has so far concentrated on the foundations of an appropriate theory. Since writing our last report, we have made further progress in formulating the basic assumptions as explicitly, rigorously and generally as possible (in order to have a safe and broad basis for later applications) and in developing the theory.

First, the concept of phase space was generalized so as to be applicable to the general-relativistic case; in contrast to other approaches no Hamiltonian structure (Poisson brackets) is assumed, only a manifold and a phase flow. The assumptions underlying the concept of a one-particle distribution function were analyzed from the Gibbsean point of view, and the condition for absence of collisions (Liouville equation) was established. Then the restrictions imposed on the distribution function by microscopic conservation laws and the corresponding macroscopic balance equations were formulated.

Next, Boltzmann's hypothesis on the frequency of collisions, modified by the requirements of modern statistics, was introduced for arbitrary collisions between an arbitrary number of particles. H-theorems and the resulting equilibrium distributions were obtained for many cases. As illustrative examples, Einstein's derivation of Planck's distribution law was generalized in our formalism, which led naturally to Toleman's relation between temperature and gravitational potential, and the radiative transfer equation was similarly rederived. Work on irreversible processes near equilibrium has been initiated.

In the course of these considerations several weaknesses and gaps of the theory have also become apparent which require further work: Does the space-time curvature of a strong gravitational field require a modification of the form of the collision-term and does it, consequently, change the H-theorem and the equilibrium distributions? Is the entropy functional in a non-stationary space-time bounded from above?

17. Spinors and Cosmology

Work on spinor analysis has continued. A book on this subject is still being actively prepared and will be published by Cambridge University Press. Several new chapters have recently been written. One of them develops a new approach to abstract spinors (and, incidentally, to tensors) depending on a dual view of indices: (i) as representing numerals and so labeling components, (ii) non-numerically denoting types of abstract objects and operations. Another chapter develops the purely geometric aspect of spinors and the geometric significance of their inherent two-valuedness. Another deals with the spinor Cartan formalism and contains several new and greatly condensed proofs of known results.

Spinors were also partly used in cosmological work which has now been published in a series of five papers. The first of these develops the method, and contains all of the homogeneous solutions of the Einstein equations for incoherent matter. The properties of one of the new families of solutions is discussed in the second paper, which points out the properties which are relevant to the interpretation of these solutions as world models. The third paper discusses the Einstein-Maxwell equations. It is shown that in the case of the electromagnetic null fields, all the homogeneous solutions are plane-fronted waves, if the cosmological term vanishes; and that there is a new type of wave for non-vanishing cosmological constant. In the case of a non-null electromagnetic field, there is a type D solution (the topological products of two spheres, first given by Robinson), and a Type 1 solution. The remaining papers deal with homogeneous solutions with dust and electromagnetic radiation. In one of these papers, there are two remarkably simple solutions which go over into the Einstein and Gödel cosmoses respectively in the limiting case as the strength of the electromagnetic field vanishes. The last paper shows that there are no homogeneous solutions with dust and electromagnetic null fields.

18. Mathematical Developments

A new formalism (closely allied to spinor formalism: less general but even more compact) has been developed which is particularly well-adapted to the construction of exact solutions and to the study of gravitational radiation. It rests on the well-known fact that in four dimensions the bivector representation of the Lorentz group is reducible. The primary object is the bundle of self-dual bivectors (i.e., symmetric 2-spinors) over the given manifold; the connection form and the curvature forms on this bundle are constructed in the usual way, and it is shown how they are related to the more classical Cartan formalism in the bundle of orthogonal frames.

When dealing with particular problems (propagation laws, asymptotic properties, exact solutions) the basic system of equations used is a system which contains the so-called metric equations, the field equations and the Bianchi identities (analogous to the Bichteler version of the Penrose-Newman spinor equations). Components of the metric, of the connection form and of the curvature form are here regarded as independent variables. There is a definite order prescribed for the integration of these equations. The most important results which have been obtained up to now are:

a. a unified treatment of most of the known algebraically degenerate solutions of Einstein's equations for empty space

b. some new solutions, which will be described in the next section

c. a simple and direct proof of the classical theorems of gravitational radiation

d. all homogeneous solutions for empty space

e. some theorems and solutions admitting "large" groups of isometries.

19. Gravitational Radiation

Electromagnetic energy in empty space has a flux $E_\wedge H$, density $1/2(E^2 + H^2)$, and consequently a velocity of $2E_\wedge H/(E^2 + H^2)$, the square of which is less than or equal to 1. These two possibilities correspond, in four-dimensional terminology, to the distinctness or coincidence of the two null rays associated with electromagnetic fields at any point. In the degenerate case, the null rays turn out to be geodetic and shear-free. This case might be described as electromagnetic radiation, in a rather stringent sense of the term. There are two obvious ways of looking for its gravitational analog: To require that either the metric should admit a null geodetic shear-free congruence or that the four null directions associated with the Weyl tensor should not all be distinct. As Goldberg and Sachs have shown, these two restrictions are, in fact, equivalent.

The first systematic attempts to obtain algebraically degenerate solutions were made by imposing the first of their restrictions on the metric. The problem then fell into three rather distinct parts, one of which, the case of twisting rays, has only been tackled in the past three years. Several groups, including ourselves, have independently succeeded in reducing the system of field equations in this case from ten to three. No general methods of integrating the reduced system have been discovered. We have, however, devised a rather more general method than was previously known for the construction of stationary solutions by modifying an appropriately chosen static solution of the twist-free expanding system. Most of the known solutions have also been rederived systematically by the techniques described under Mathematical Development. These methods have also been used for the investigation of null gravitational fields in the presence of electromagnetic fields, and all the twist-free solutions have been obtained.

20. Classical Relativity

Six months ago, we reported on work in which we deduced from the (special) relativity principle and the conservation of energy in particle collisions (i) the form of the energy function, and (ii) the conservation of inertial mass and three-momentum. A considerable simplification in the proof has now been achieved, together with a sharpening of the original assumptions. A second paper on the subject is in press, which also contains the parallel development of Newtonian mechanics.

A puzzling point in the well-known Kruskal-Schwarzschild metric of an isolated mass point in general relativity is the sudden reversal in the direction of penetrability of the event-horizon at one given instant. By finding a "cosmological" version of this metric in the form of a test gas which first explodes and then implodes, we have succeeded in understanding physically the properties of the horizon. A paper on this subject is in preparation.

21. Equation of Motion

Standard approximation methods in Einstein's general theory of relativity build a solution to the field equations by means of an expansion of the metric in a power series of a parameter, using the Minkowskian metric as a background field. For a confined distribution of matter (enclosed in a cylinder with topology $S^2 \times R^1$) it is not known how to choose the solution in order that the metric at spatial infinity is the Minkowskian metric. We are investigating this important problem in the case in which the matter distribution admits a time-like Killing vector field (i.e., is stationary), and has a finite number of multipole moments with respect to this Killing field. With these restrictions, we are in the process of demonstrating the required asymptotic behavior of the solution.

22. Elementary Particles

A joint paper by Yuval Ne'eman and Istvan Ozsvath described in our former report has appeared since in the Physical Review.

Among the problems most recently under consideration, we should like to mention the problem of the Spectrum Generating Algebras (SGA). It is an outgrowth of two new ideas applied to particle physics (1-4): The one is physical, the other is mathematical. Physically one extends the algebraic approach to include algebras which do not generate symmetries, mathematically one makes use of infinite dimensional unitary representations of non-compact groups.

The whole scheme exists as yet in somewhat sketchy outline. Our point would be to study the idea on examples, i.e., in quantum mechanics in order to formulate a precise definition of the term SGA and apply it to problems of particle physics. We studied among others the case of the three-dimensional hermonic oscillator, where the symmetry group is the compact U(3) group, but as it turned out, the states can be characterized as base vectors of Hilbert space supporting a special infinite dimensional Unitary representation - the so-called ladder representation - of the non-compact U(1,3) group. We would say therefore that the SGA of the oscillator problem is the Lie algebra of the group U(1,3).

We intend to study the case of Schroedinger's equations with square well and Yukawa potentials and we hope to be able to produce a useful definition for applications to particle physics. (The SGA of the Yukawa case might have direct applications already.) We plan to write a joint paper on this subject for the Journal of Mathematical Physics.

Another question we might study is a suggestion of F. Zachariasen to try to explain the mass difference between neutral and charged pions as electromagnetic mass difference applying methods used by Dashen and Frautschi to obtain the proton-neutron mass difference. If the problem is feasible, we will carry it out in cooperation with F. Zachariasen.

C. Space Technology

Previous efforts in the area of space technology at SCAS are now visibly "bearing fruit," as evidenced by the results of the first flight of the Multiple Ionospheric Probe experimental rocket. The Engineering Support Group (ESG), under the direction of R. Bickel, produced the payload structure, power supplies, and programmer for this highly complex and successful experiment. In addition, the ESG specified and acquired the clam-shell nose cone, a thirty channel commutator, and numerous smaller items such as timers, test fixtures, etc.

The MIP power supply operates from the twenty-eight volt battery pack and supplies outputs at -100v, +50v, -18v, +18v, and +6.3 volts. It delivers a maximum of 65 watts with about 75% efficiency. Each output is isolated so that a failure within any experimental package, which causes an overload or short circuit on the power supply outputs, will have no effect on the other experiments. The lower voltage outputs have load limiting circuits which will reestablish the output voltages, if the fault is cleared. This unit is built in a shielded case which requires only two inches of height in the payload rack. The shielding prevents radiation of the switching transients from the inverter. The power supply is connected to the battery package to gain additional heat absorbing mass.

The MIP programmer, which controls the timing and sequencing of the various experiments, is designed to continue partial operation if a failure should occur in the timing chain. This partial operation will somewhat reduce the information to be obtained, but it will allow the accumulation of some data and also permit the analysis of the failure mode. This unit was designed by utilizing switching circuit techniques similar to those used in computer design.

The prototype model of the Cosmic-Ray Anisotropy experiment for the IMP "F" and "G" satellites has been shown to NASA at Goddard on a first look basis. The Engineering Support Group is responsible for the electronics design and construction of this experimental package. There were many favorable comments concerning its professional appearance and our promptness in presenting this unit. The final adjustments are now being made on the prototype (flyable) model, and then it will be tested under thermal-vacuum conditions. It should be delivered on scheduled. The first and second flight units are now being assembled and should also be delivered on time. The thermal-vacuum test facilities for this program was also designed and constructed by the ESG and is now ready for use.

The drafting group has designed equipment for the ISIS satellite experiment, and in addition it has prepared a substantial number of figures and slides for various papers and reports.

The machine shop is about to be moved into the basement of the Founders Building where the additional area and facilities will contribute to greater efficiency and capabilities. This will help expedite the new rocket and satellite programs which are now being initiated.

D. Other Support to NASA

SCAS provides additional support to NASA in several ways. Drs. F. S. Johnson, W. B. Hanson, and K. G. McCracken serve on the Planetary Atmospheres, Ionospheres and Radio Physics, and Particle and Fields subcommittees of NASA's Space Science Steering Committee, respectively.

Dr. F. S. Johnson serves as Chairman, Lunar Atmosphere Measurement Team of the Apollo Science Planning Teams, and as a member of the Voyager Capsule Advisor Group.

E. Contracts and Grants

"A Comparison of Rocket-Borne Probes for Electron Density Measurements," NASA Contract NSR 44-004-017, J. A. Fejer, W. J. Heikkila, and O. Holt

"Investigations of the Neutral Composition of the Upper Atmosphere," NASA Contract NASr-177, W. B. Hanson and T. W. Flowerday

"Investigations into the Mechanism and Rates of Atmospheric Mixing in the Lower Thermosphere," NASA Grant NGR 44-004-026, F. S. Johnson

"Laboratory Studies of Electron Collision Frequency under Ionospheric Conditions," NASA Grant NGR 44-004-030, W. J. Heikkila

"Measurement of the Degree of Anisotropy of the Cosmic Radiation Using the IMP Space Vehicle, NASA Contract NAS5-9075, K. G. McCracken, W. C. Bartley, and U. R. Rao

"Measurement of the Degree of Anisotropies of the Cosmic Radiation Using the IQSY Vehicle (PIQSY)," NASA Contract NAS2-1756, K. G. McCracken, W. C. Bartley, and U. R. Rao

"Multidisciplinary Research in Space-Related Science and Technology," NASA Grant NsG-269-62, L. V. Berkner

"Procurement and Test of a Prototype Coincidence Mass Spectrometer for Use in Apollo Missions and Generation of Specifications for a Proof Test Instrument," NASA Contract NAS 9-4830, F. S. Johnson

"A Soft-Particle Spectrometer for the ISIS-A Satellite," NASA Contract NAS5-9112, W. J. Heikkila

"To Develop and Evaluate Techniques and Instrumentation for the Measurement of Cosmic Radiation Anisotropies," NASA Contract NASr-198, K. G. McCracken

"Acquisition and Operation of Super-Neutron Monitor Stations to Advance the Study of Cosmic Ray Anisotropy and Other Phenomena Associated with Energetic Particles," NSF Grant GP-926, K. G. McCracken

"A Co-operative Onshore-Offshore Seismic Experiment," AFCRL Contract AF49(638)-1542, A. L. Hales

"A Facilities Grant for Construction of a Mass Spectrometer for Potassium-Argon Analysis," NSF Grant GP-4170, H. Faul

"A Mathematical Theory of the History of the Earth's Atmosphere," NSF Grant GP-4708 (formerly GP-768), L. V. Berkner and L. C. Marshall

"Analysis of Coexisting Minerals of Garnet-Peridotites from a Number of Kimberlite Pipes in the South African Shield," NSF Grant, B. T. C. Davis and I. D. MacGregor

"Analysis of the Super-Neutron Monitor Data Obtained During the IQSY," NSF Grant GP-4688, K. G. McCracken

"Geochronologic Study of Igneous and Metamorphic Rocks in the Southern

Cordillera of Tierra del Fuego, Chile," NSF Grant GA-176, M. Halpern and H. Faul

"Geomagnetic Variations in the Upper Mantle," NSF Grant GP-4650, D. I. Gough

"Gravity Study," D. I. Gough. This work is being done under Air Force Contract AF61(052)656 in collaboration with the Observatorio Geofisico Sperimentale, Trieste, Italy, the original contractor.

"Ground-Based Studies of the Geocorona Hα Emission and Some Other Night Sky Emissions, with a Grille Spectrometer," NSF Grant GP-3950, F. S. Johnson and B. A. Tinsley

"Infrared Absorption Studies," AFCRL Grant AF19(628)-5039, G. N. Plass

"Marine Geophysics Program," ONR Contract Nonr-4455(01), A. L. Hales

"Measurement of Heat Flow in Thermally Stable Lakes," NSF Grant GP-1910, J. S. Reitzel

"A Program for the Measurement of the Response of the Earth's Crust to Surface Loading," NSF Grant GP-1335, A. L. Hales

"A Program for Paleomagnetic Research," NSF Grant GP-4099 (formerly GP-1454), J. W. Graham

"Research Directed Toward Detecting Regional Differences in the Earth's Mantle," AFCRL Contract AF19(628)-2936, A. L. Hales

"Research on General Theorems on Singularities in Spatially Homogeneous Cosmological Models," AFOSR Grant AF-AFOSR-903-65, I. Ozsvath, W. Rindler, and I. Robinson

"Research Program to Provide Information on the Primary Hydromagnetic Spectrum," NSF Grant GP-4339 (formerly GP-2907), J. A. Fejer

"The Spatial Relationships of the Earth's Major Surficial Features During Portions of Cretaceous Time," NSF Grant GP-2205, C. E. Helsley

"A Study of the Interplanetary Magnetic Field and Its Effect upon the Cosmic Radiation," AFCRL Contract AF19(628)-5028, K. G. McCracken

"A Study of the Paleomagnetism of Permian and Precambrian Rocks in North America," American Chemical Society Grant PRF 1829-A-2, C. E. Helsley. (This grant is administered through Southern Methodist University.)

F. Publications

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McCracken, K. G., U. R. Rao, B. C. Fowler, M. A. Shea, and D. F. Smart, "Cosmic ray asymptotic directions, variational coefficients and cut-off rigidities," IQSY Instruction Manuel No. 10, 1965.

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Ozsvath, I., "New homogeneous solutions of Einstein's field equations with incoherent matter," Akademie de Wissenschaften und der Literature, Mainz, 1-31, 1965.

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Ozsvath, I. and Y. Ne'eman, "Unitary symmetry viewed as a broken rotational invariance," Physical Review, 138, B1474-1487, 1965.

Tinsley, B. A., L. E. J. Montbriand, and A. Vallance Jones, "Galactic hydrogen as a hazard in auroral spectroscopy," Can. J. Phys., 43, 782-792, 1965.

G. Papers Presented at Scientific Meetings

Berkner, L. V. and L. C. Marshall - Evolution of the earth's atmosphere, National Academy of Sciences, Washington, D. C., April 26, 1965

Berkner, L. V. and L. C. Marshall - The air we breathe, Bohemian Grove Lakeside Talk, July 22, 1965

Berkner, L. V. and L. C. Marshall - The rise of oxygen in the earth's atmosphere, Fifth Western National Meeting of the American Geophysical Union, Southern Methodist University, Dallas, Texas, September 1, 1965

Colegrove, F. D., W. B. Hanson, and F. S. Johnson - Vertical transport of oxygen between 80 to 120 km, American Geophysical Union 46th Annual Meeting, Washington, D. C., April 19-22, 1965

Colegrove, F. D, W. B. Hanson, and F. S. Johnson - Neutral composition of the upper atmosphere, Fifth Western National Meeting of the American Geophysical Union, Southern Methodist University, Dallas, Texas, September 3, 1965

Ehlers, Jürgen - The physics of gravitation, Richardson High School Combined Science Clubs, Richardson, Texas, March 30, 1965

Fejer, J. A. and W. D. Deering - Excitation of plasma resonances by a small pulsed dipole antenna, Colloquium on Antennas on Ionized Environment, Paris, France, June 21-25, 1965

Flowerday, T. W. - Experiments in space, Town North Civitan, Dallas, Texas, September 15, 1965

Hanson, W. B. and R. J. Moffett - The effect of ionization transport on the equatorial F-region, Second International Symposium on Equatorial Aeronomy, Sao Paulo, Brazil, September 6-17, 1965

Heikkila, W. J. - Optimum instrumentation for the high frequency capacitance probe; Impedance and conductivity probes; Report on multiple ionospheric probe rocket experiment; Impedance and conductivity, Second Conference on Direct Aeronomic Measurements in the Lower Ionosphere, University of Illinois, Urbana, Illinois, September 27-30, 1965

Helsley, C. E. - Paleomagnetic results from the middle Cambrian of northwest Africa; Paleomagnetic results from Precambrian rocks of central Arizona and Duluth, Minnesota, American Geophysical Union Meeting, Washington, D. C., April 19-22, 1965

Hoffman, A. A. J. - Applications of numerical filters in the power spectral analysis of stationary time series, SWIEEECO 1965 Meeting, Dallas, Texas, April 21, 1965

Holmquist, F. N. - A proposed induction probe for ionospheric studies, Second Conference on Direct Aeronomic Measurements in the Lower Ionosphere, University of Illinois, Urbana, Illinois, September 27-30, 1965

Hurt, W. B. - Spatial distribution of radiation in a helium negative glow, Fourth International Conference on the Physics of Electronic and Atomic Collisions, Quebec, Canada, August 2-6, 1965

Hurt, W. B. and C. B. Collins - Optical pumping of the positive column of a helium dc discharge, Seventh International Conference on Phenomena in Ionized Gases, Beograd, Yugoslavia, August 30-September 4, 1965

Johnson, F. S. - Ionospheric measurements, National Telemetering Conference, Houston, Texas, April 15, 1965

Johnson, F. S. - Lunar atmospheric measurements for the Apollo program, Lunar Exploration Symposium, Marshall Space Flight Center, Huntsville, Alabama, April 28, 1965

Johnson, F. S. - Eddy diffusion in the lower thermosphere, COSPAR Sixth International Space Science Symposium, Mar del Plata, Argentina, May 17, 1965

Johnson, F. S. - Report on sixth international space science symposium of COSPAR, SCAS, Dallas, Texas, June 21, 1965

Johnson, F. S. - Planetary atmospheres; Interplanetary space, Summer Institute in Astronomy for High School Teachers of Science and Math, Sam Houston State Teachers College, Hunsville, Texas, July 8-9, 1965

Johnson, F. S. - Density of an exosphere, IAGA Symposium on Density and Composition of the Upper Atmosphere, Cambridge, Massachusetts, August 17, 1965

Johnson, F. S., F. D. Colegrove, and W. B. Hanson - Turbopause processes and effects, Second Conference on Direct Aeronomic Measurements in the Lower Ionosphere, University of Illinois, Urbana, Illinois, September 29, 1965

Landisman, M. and S. Mueller - Seismic studies of the earth's crust, Seismological Society of America Meeting, St. Louis University, St. Louis, Missouri, April 12-14, 1965

Landisman, M. and S. Mueller - Seismic studies of the earth's crust, Second International Symposium on Geophysical Theory and Computers, Weizmann Institute, Rehovoth, Israel, June 13-23, 1965

Liemohn, H. B. and L. L. Baggerly - Report on the Advanced Study Institute held in Bergen, Norway on August 16-September 3, SCAS, Dallas, Texas, September 21, 1965

McCracken, K. G. and H. S. Ahluwalia - The influence of the magnetopause on cosmic ray particle trajectories, Ninth International Conference on Cosmic Rays, London, England, September 6-17, 1965

McCracken, K. G. - Raporteur paper summing up the status of the field of cosmic ray modulation research, Ninth International Conference on Cosmic Rays, London, England, September 6-17, 1965

Oetking, P. - A possible contributing cause of the increased brightness of the full moon, American Geophysical Union Meeting, Washington, D. C., April 19-22, 1965

Oetking, P. - The moon, Lions Club, McKinney, Texas, April 28, 1965

Oetking, P. - Features of the moon, Farmersville Rotary Club, Farmersville, Texas, May 11, 1965

Oetking, P. - Can man land on the moon?, McKinney Men's Club, McKinney, Texas, May 19, 1965

Oetking, P. - Earth vs. moon, Junior Science Academy, Dallas Health and Science Museum, Dallas, Texas, June 24, 1965

Oetking, P. - The moon, Summer Institute of Science and Math Teachers, Texas Christian University, Ft. Worth, Texas, July 8, 1965

Oetking, P. - Lunar geology, Summer Science Session, Saint Mark's School, Dallas, Texas, July 13, 1965

Plass, G. N. - The theory of the absorption of flame radiation by molecular bands, Eighth European Congress on Molecular Spectroscopy, Copenhagen, Denmark, August 14-21, 1965

Robinson, I. - Relativity, Hillcrest High School Science Club Meeting, Dallas, Texas, April 1, 1965

Tinsley, B. A. - The grille spectrometer, Society for Applied Spectroscopy, Dallas, Texas, April 12, 1965

H. Lectures by Visiting Scientists

Boyer, Robert - An Extension of the Kerr Metric, June 10, 1965, Liverpool University and The University of Texas

Bridges, Herb, Stanislaus Olbert, and Bud Lyon - Preliminary Results of the MIP Satellite Plasma Probes, June 21, 1965, Massachusetts Institute of Technology, Cambridge, Massachusetts

Carmichael, Hugh - Interplanetary Magnetic Fields, Particles and Flares, May 26, 1965, Atomic Energy of Canada, Limited, Chalk River, Canada

Cohen, Robert - Ionospheric Report from the Jicarmarca Radar Observatory, May 20, 1965, National Bureau of Standards, Boulder, Colorado

Farmer, C. B. - Atmospheric Transmission Studies at E.M.I. Electronics Ltd., April 5, 1965, E.M.I. Electronics Ltd., Feltham, Middlesex, England

Hodges, Richard - Gyro-Interaction Rocket Experiments in the Lower Ionosphere, April 26, 1965, Collins Radio Company, Richardson, Texas

Kerr, Roy - The Uniqueness of the Ozsvath Solutions of the Cosmological Field Equations, May 28, 1965, The University of Texas, Austin, Texas

Mebane, W. M. - Evolution of the Space Age, April 7, 1965, Thiokol Chemical Corporation, Bristol, Pennsylvania

Patel, V. L. - Results of the Magnetic Field Measurements from Explorer 12 and Explorer 14, June 22, 1965, University of New Hampshire

Skadron, George - Aspects of the Origin of Primary Cosmic Radiation, May 18, 1965, University of Rochester

Virma, Ray - Geophysical Activities in India, April 15, 1965, National Geophysical Institute, Hyderabad, India

Wyler, Oswald - Exterior Differential Calculus; Maxwell's Equations; Integration on Clans and Tribes, April 2, 1965, University of New Mexico

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Anderson, Mr. John E. (Instrument Maker)
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Bohlander, Mr. Ronald A. (Summer Technician)
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Tittle, Mr. Richard L. (Summer Technician)
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Toney, Mr. James B. (Electronics Technician)
Verhoogen, Dr. John (Consulting Professor)
Walker, Mr. E. Alan (Illustrator)
Wheless, Mr. J. E. (Mechanical Designer)
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Williams, Mr. Neal (Summer Technician)
Wilson, Mr. Warren L. (Electronics Technician)
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Wong, Mr. Victor M. (Mechanical Engineer)
Wright, Mr. W. H. (Research Associate)
York, Mr. Douglas (Laboratory Technician)
York, Mr. James E. (Draftsman)
Younse, Mr. Jack M. (Electronics Engineer)
Zund, Dr. Joanna M. (Research Associate)
Zund, Dr. Joseph D. (Research Associate)

J. Symposia

Cahen, Michel - "Pure Gravitational Waves," Yeshiva University, New York City, New York, May 17, 1965

Cahen, Michel - "Gravitational Waves and Matter," Syracuse University, Syracuse, New York, May 19, 1965

Cahen, Michel - "Gravitational Radiation," Ohio State University, May 20, 1965

Deering, W. D. - "Plasma Kinetic Theory," Texas Technological College, Lubbock, Texas, April 12, 1965

Fejer, J. A. - "Excitation of Plasma Resonances by a Short Pulsed Dipole Antenna," Cornell University, Ithaca, New York, April 28, 1965

Johnson, F. S. - "Frontiers in Geophysics," AGU Visiting Scientists Program, Texas Women's University, Denton, Texas, April 6, 1965

Johnson, F. S. - "Frontiers in Geophysics" and "The Exploration of Space," AGU Visiting Scientists Program, Midwestern University, Wichita Falls, Texas, April 7, 1965

Johnson, F. S. - "The Lower Thermosphere," Rice University, Houston, Texas, April 15, 1965

Ozsváth, István - "Mach Principle," Observatory in Hamburg, , June 11, 1965

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